SUDBURY AREA RISK ASSESSMENT

CHAPTER 4.0
REGREENING AND THE CHANGING LANDSCAPE

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4.0 REGREENING AND THE CHANGING LANDSCAPE

The term "regreening" was coined to describe the reclamation activities that have re-established forest and vegetation cover on industrially damaged land in the Sudbury Region. The regreening of Sudbury began as far back as 1917, when Inco Ltd. converted an old tailings area into a grassed community park. The mining companies (Inco Ltd. and Falconbridge Ltd.) expanded their reclamation activities in the 1960s in response to increased public concern about the environment. Community initiatives evolved in May, 1978, into one of the largest documented community-based reclamation programs for industrially disturbed lands: the City of Sudbury's Land Reclamation Program (Lautenbach, 1985). The regional regreening program has applied a "minimal intervention" approach to reclamation that has successfully triggered natural and assisted revegetation of the landscape.

By the end of 2005, 3,367 ha had been treated by the Land Reclamation Program. Although impressive in its scope, given estimates of well over 80,000 ha of land affected by past mining activities, the task of land reclamation remains daunting. While past regreening initiatives focused on aesthetic improvements, recent efforts have turned toward creating self-sustaining plant communities that more closely resemble pre-mining forest communities. Identifying impediments to revegetation has also provided the impetus for Objective #1 of the Ecological Risk Assessment (ERA) of the Sudbury Soils Study (Chapter 3 of Volume III).

This chapter presents an overview of the regreening initiatives, including both the technical and socio-economic facets of the programs, as well as presenting the following information:

- An overview of the historical conditions that led to the regreening efforts;
- A review of historical and current vegetation in the region affected by smelting, with a focus on the barren and semi-barren areas (defined in detail below); and
- A summary of continuing impediments to regeneration.

4.1 Historical Context: Legacy of Mining and Smelting

Sudbury is known globally as a leading nickel producer, and was in the past one of the largest point sources of acid-forming emissions in the world. More than 100 million tonnes of sulphur dioxide and tens of thousands of tonnes of metal particulates (primarily copper and nickel) were released into the atmosphere from smelters over the past century (Lautenbach, 1985). These emissions led to the acidification and metal-loading of soils in a large area around the smelters, the acidification of over 7,000 lakes and a dramatic decline in vegetation within a deposition zone of 17,000 square kilometres in the Sudbury Region (Gunn, 1996).

Before the smelter emissions began, frequent fires set to enhance mineral prospecting in the late 1800s and lightning-triggered fires that ignited the highly flammable drought-stressed vegetation had already killed and/or reduced the recovery of vegetation in the Sudbury area (Courtin, 1994; Lautenbach, 1985). The result of these fires were barren areas that covered approximately 20,000 ha, with an additional approximately 80,000 ha classified as semi-barren (defined in detail below). From 1900 to 1980, Sudbury possessed a reputation as a "moonscape" largely devoid of forest cover (Winterhalder, 1996; Lautenbach, 1985).

In addition, many of the eight to 10 million tonnes of tailings and slag produced each year (Peters, 1995) have been stored at the surface, creating unsuitable substrates for natural regeneration (Winterhalder, 1996). At Copper Cliff alone, the iron, copper and nickel sulphide (6:1:1 ratio) tailings cover an area of over 2,225 ha (Winterhalder, 1995a). These materials can result in acid mine drainage and/or the creation of dust "clouds" that are deposited in adjacent areas when the surface dries out (Bouillon, 1995).

Slag deposits from ore processing (Figure 4-1), produced at a rate of nine tonnes per 100 tonnes of smelted ore, have also been stored at the surface, creating over 119 million tonnes of slag at Vale Inco Ltd. operations, and 10 million tonnes on Xstrata Nickel land (Heale, 1995). These materials create a harsh, inhospitable surface for vegetation establishment. Some of Inco's slow-cooled slag has been crushed and sold as road material in recent years, which reduces the land lost to storage (Winterhalder, 1996). Xstrata's water-cooled, granulated slag has been largely stored at surface, creating a different but equally sterile material for revegetation efforts.

Figure 4-1 Inco slag piles viewed from the west side of Sudbury

4.1.1 The Forests Prior to 1900: Pre-industrial Landscape

Sudbury lies within an area classified as the Great Lakes-St. Lawrence Forest Region (Rowe, 1959). It is located on the southern margin of the Northern Temagami Section, characterized by large stands of red pine (*Pinus resinosa*) and white pine (*Pinus strobus*), and the northern margin of the Southern Algonquin Section, where white pine and eastern hemlock (*Tsuga canadensis*) grew among sugar maple (*Acer saccharum*) and red oak (*Quercus rubra*) hardwoods in the uplands. Black ash (*Fraxinus nigra*), yellow birch (*Betula allegheniensis*) and eastern white cedar (*Thuja occidentalis*) occupied the depressions. Understory plant diversity was greatest in the nutrient-rich, moist lowland black ash swamps and was variable with stand age and overstory composition in the upland forests. Evidence of the former forests can be seen as remnant burnt white pine stumps (Figure 4-2) in the uplands and remnant eastern white cedar stumps in barren peatland (Winterhalder, 2002).

Figure 4-2 Remnant burnt white pine stumps

4.1.2 The Forests of the Early 1900s: Harvesting and Fire Damage

The pre-colonization Tolerant Hardwood-Pine-Mixed Forests of the Sudbury area were first modified with the selective harvest of red pine and white pine from 1872 to the mid-1920s. Large volumes of wood were harvested to rebuild Chicago following the "great fire" of 1871 (Winterhalder, 2002; Chislett, 1983). Logging continued to selectively remove conifer species in the outlying areas for lumber, pulp, and railway ties, with conifer forests replaced by the more rapidly growing white birch (*Betula papyrifera*) and trembling aspen (*Populus tremuloides*) (Winterhalder, 2002). The slash left on site from logging fuelled frequent forest fires, which were often started by sparks from the railway.

Prospectors often set fires to burn off the ground cover to expose the bedrock (Chislett, 1983). This further modified the natural cycle of fire and recovery, shifting plant composition to favour species that establish following fire. For example, lowbush blueberry (*Vaccinium angustifolium*) populations thrived in the open areas, proliferating on sites that experienced periodic fires (Winterhalder, 2002). Frequent or hot summer fires also burned off the surface organic layers on the shallow-soiled hilltops, accelerating soil loss due to erosion.

By the turn of the century, black spruce (*Picea mariana*), white spruce (*Picea glauca*), balsam fir (*Abies balsamea*) and much later, jack pine (*Pinus banksiana*) were harvested for lumber and pulp, as well as for fuel for train locomotives and to create roast beds in the early smelting of nickel ore in the late 1800s and early 1900s. Pollen studies of lake sediment cores extracted near the Coniston smelter indicate that birch replaced pine and spruce-dominated forests in the early 1940s (Winterhalder, 1996). The absence of white pine within 24 km of the Xstrata Nickel smelter reflects both its historic removal and its lack of tolerance to sulphur dioxide fumigations. This prevented its re-establishment following logging and land clearing (Gorham and Gordon, 1960a).

4.1.3 Roasting Yard Impact

A description of the historical ore roasting beds was provided in Chapters 2 and 3 and is briefly summarized here. Nickel-rich ore was piled on cords of wood in over 165 roasting beds at 11 locations between 1888 and 1929 to burn off sulphur contaminants prior to smelting (Laroche *et al*., 1979). In 1916, smelting was directed to one very large roast yard at the O'Donnell site, 20 km west-southwest of Sudbury. Between 1913 and 1916 the Mond Nickel Company removed all of the trees and stumps from the Coniston area to feed the roast beds (Watson and Richardson, 1972). Most of the small roast yards, where they do not occur adjacent to more recent smelters, have been recolonized by native plant species and provide a source of nickel- and copper-tolerant strains of native vegetation (Hogan *et al*., 1977). Metal stress remains present in the adjacent forests with elevated copper and nickel levels (100 µg/g Ni and 7 µg/g Cu) measured in white birch leaves in the late 1990s (Hutchinson and Symington, 1997). The lasting impact of the smaller roast beds is minimal.

The larger O'Donnell roast yard, which closed in 1929, created a longer-term impact on the vegetation in the area. Recovery patterns documented by Struik (1974) showed that within 20 years, shrubs invaded the site, forming scattered patches. By 1959, white birch and trembling aspen had successfully invaded these shrub "refugia". By 1973, the treed cover still formed distinct patches. By 2002, the deciduous forest canopy in the forests surrounding the old roast yard had closed in and supported an understory of wavy hairgrass (*Deschampsia flexuosa*). Plant cover on the roast yard itself remains light (Figure 4-3), dominated by a few grass species and scattered sheep laurel (*Kalmia angustifolia*).

Figure 4-3 O'Donnell roast yards, circa 1974

4.1.4 The Forests of the Mid-to-Late 1900s: Emissions Damage

The region's forests were further modified by poor air and soil quality associated with smelting ore. Sulphur dioxide damage to poplar, white birch and cultivated plants has been repeatedly documented, with damage to trembling aspen observed as far as 100 km east and 77 km southwest of the City of Sudbury (OMNR, 1982; McIlveen and Balsillie, 1978; McGovern and Balsillie, 1972; 1973; 1975; Dreisinger and McGovern, 1969). Hutchinson and Whitby (1974) estimated that vegetation damage covered more than 5,180 km^2 (see Chapter 3 for a detailed emissions history).

Emissions from the stacks include sulphur dioxide and particulates of iron, copper and nickel (Chislett, 1983). The sulphur dioxide, oxidized and mixed with rain, created acids that leached nutrients from the organic-poor soils and mobilized metals deposited from the emissions. A combination of acidic soils and metal absorption led to mortality of all but the metal-tolerant vegetation species or strains (Chislett, 1983).

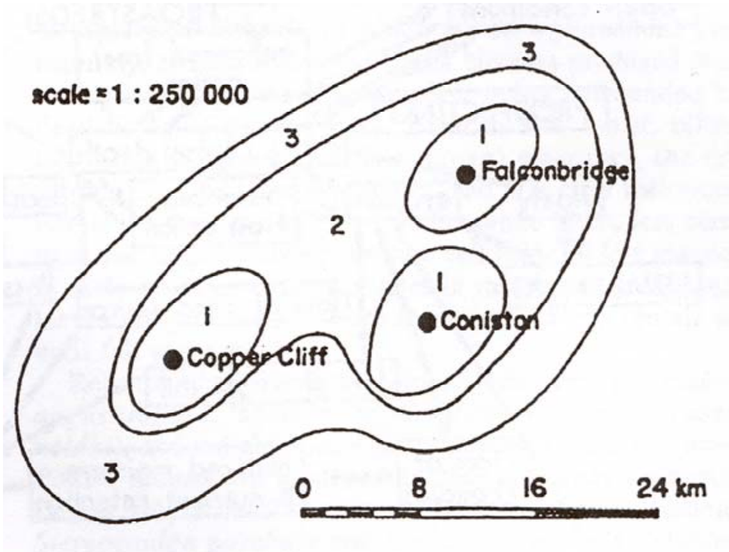
Dramatic reductions in the diversity of forest understory plant species and pollution-intolerant lichens have been documented by Hutchinson and Whitby (1974), Winterhalder (2002) and many others. The variety of understory species remains small, including lowbush blueberry (*Vaccinium augustifolium*), wavy hairgrass (*Deschampsia flexuosa*), rough bentgrass (*Agrostis scabra*), bracken fern (*Pteridium aquilinum*), and, less commonly, wintergreen (*Gaultheria procumbens*) and wild lily-of-the-valley

(*Maianthemum canadense*). Even the diversity of mosses is limited. Arboreal lichen remains limited to absent on trees at sites as far as Grundy Provincial Park, located almost 100 km south of Sudbury. A more detailed discussion of changes in plant species composition is provided in the following sections.

4.2 Smelter-Affected Areas: The Barrens and Semi-barrens

The most dramatic industry-related changes to the area's forest cover remain clearly visible in disturbed areas centred on former low smokestacks in Copper Cliff, Coniston and Falconbridge, which were built in 1929 and 1930 and closed in the 1970s. H. Struik, a forester with OMNR, produced the first direct measure of the extent of vegetation damage throughout the Sudbury area (Winterhalder, 1995). Using air photographs, he mapped zones of site and plant community stability, delineating three elliptical circles of barrens centred on the three smokestacks (Figure 4-4 barren areas). The barrens (Figure 4-5) occupied the area mapped by Struik (1973) as unstable. McCall *et al.* (1995) calculated the area of severe barrens at nearly 20,000 ha, with an additional 80,000 ha semi-barren area. These zones were very similar to the pollution zones mapped by Dreisinger and McGovern (1969). The barrens were also clearly visible in satellite images analysed by Pitblado and Amiro (1982), Lynham and Pierce (1997) and most recently as part of the Sudbury Soils Study (see Chapter 5 for remote sensing information).

In 1981, Amiro and Courtin (1981) provided the first detailed description of vegetation within these smelter-affected areas. The severe barren area was labelled the "Barren", which was largely devoid of tree cover and defined by soils of pH 4.0 and lower. Three of Amiro and Courtin's plant communities—the "Birch Transition", "Maple Transition" and "Red Oak" communities—together make up the 80,000 ha of semi-barren land more distant from the smelters, which supports a savannah-like cover of stunted, well-spaced clusters of coppice-origin white birch (*Betula papyrifera*) and red maple (*Acer rubrum*) woodlands (Courtin, 1994; Winterhalder, 2002; Gunn, 1996). The vegetation of the barren and semi-barren areas is discussed in detail below. The recovery and regeneration of the vegetation in these regions is investigated using remote sensing techniques in Chapter 5.



Zone 1: Barren sites

Zone 2: Semibarren sites

Zone 3: Normal sites

Source: Winterhalder, 1996

Figure 4-4 Map of 3 barren areas (vegetation zones)

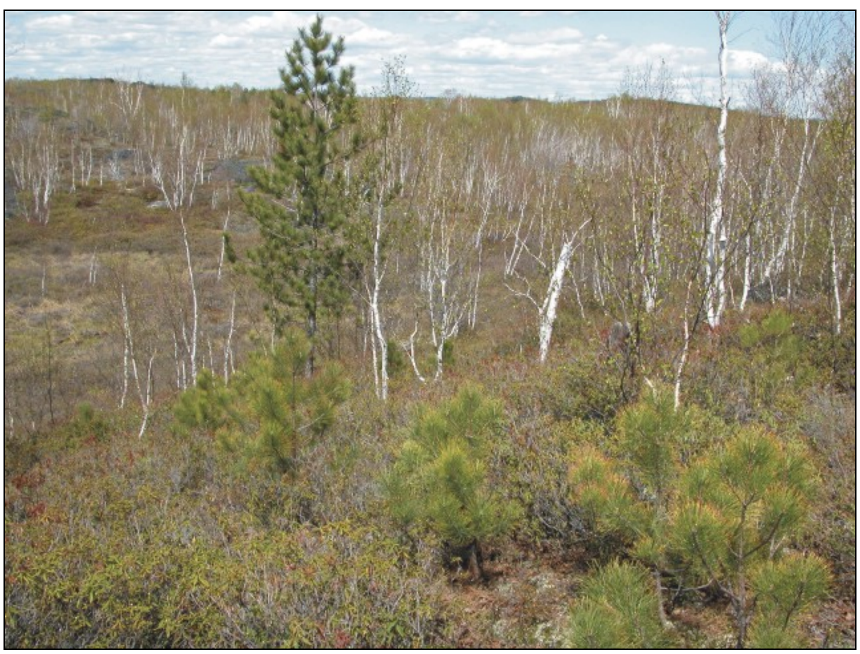


Figure 4-5 Photo of revegetating barrens

4.2.1 Vegetation in the Barrens

Copper and nickel levels are significantly higher in soils close to the smelters. The observed levels could impede the recolonization of these sites by native plant species even after emission reductions (Winterhalder, 1975; Hutchinson and Whitby, 1974). Objective 1 of the ERA (Volume III) investigates whether the level of metals in the soil at a variety of sites in the Sudbury region are impeding recovery of self-sustaining forest communities in these regions. In the barrens the only plants still surviving are depauperate residual trees species, including stunted and deformed coppice-origin white birch, red maple, and red oak on upland and dry sites and understory species that are metal-tolerant. On fresh to moist sites, trembling aspen occur as clonal patches from root suckers (Winterhalder, 1996). The maples continue to display regressive dieback characterized by reddening and early senescence of foliage, and an annual reduction of living biomass surrounded by dead limbs. Relict white birch often show premature yellowing of leaf margins in early summer but additional leaves are produced later in the season (Winterhalder, 1996; McIlveen and Negusanti, 1984; James, 1982).

The most common residual shrub in the barrens is lowbush blueberry. Less common are northern wild-raisin (*Viburnum cassinoides*) and red-berried elder (*Sambucus pubens*). Metal-tolerant wavy hairgrass has also colonized the barrens, forming scattered patches (Hogan *et al*., 1977).

Some species of lichens are common in the Sudbury area (Figure 4-6), but overall, species diversity is low. The moss, *Pohlia nutans,* is common in seepage areas on northern facing slopes sometimes associated with the two pollution-tolerant lichens, *Stereocaulon paschale* and *Cladonia deformis* (Nieboer *et al*., 1972). Moss protenemata (usually *Pohlia nutans*) often form a cryptogamic mat on barren soils. Moss occupies the niche commonly occupied by filamentous algae outside the industrially impacted zone, and in low, moist areas, tufted hair grass forms meadows (Winterhalder, 1996). Early studies also showed that the only lichen that survived in this zone were crustose lichen and rock-encrusting *Stereocaulon* spp. (probably *S. saxatile* or *S. paschale*), with a few occurrences of *Parmelia physodes* (=*Hypogymnia physodes*) and *P. saxatilis* occurring in the outer fringe of this zone (Nieboer *et al*., 1972). Even as late as the 1970s, attempts to transplant lichen into this zone were unsuccessful (LeBlanc and Rao, 1973; 1966). However, the pollution–tolerant lichens, *Stereocaulon paschale* and *Cladonia deformis* (Nieboer *et al*., 1972), colonize residual organic matter on the blackened bedrock outcrops.

Figure 4-6 *Stereocaulon* lichen with fungi (Photo courtesy of the City of Greater Sudbury Land Reclamation Program)

4.2.2 Vegetation in the Semi-Barrens

Surrounding the barrens are the open, stunted, semi-barren white birch, red oak (on the driest upland hills), and in the past, red maple transition stands, characterized by a sparse understory between multi-stemmed white birch, red maple, and red oak (Winterhalder, 1996). The white birch continues to re-sprout with select individual stems increasing in diameter and height (Figure 4-8). On some sites, premature yellowing occurs on the margins of leaves in early summer (McIlveen and Negusanti, 1984) but is followed by the production of green long shoot leaves later in the season. Pollen from sediment cores indicates that the replacement of the pre-disturbance spruce and pine forests occurred around 1940 (Winterhalder, 2002).

Figure 4-7 Resprouting white birch (Photo courtesy of the City of Greater Sudbury Land Reclamation Program)

Over the past years, red maple has not fared as well, and continues to decline. The residual red maples show "regressive dieback" whereby foliage reddens prematurely, stems surrounding the stool are continually replaced by smaller stems, and the amount of annual living biomass gradually decreases. Sinclair's (1996) work showed that the Maple Transition communities of Amiro and Courtin (1981) had largely disappeared due to this dieback. During dieback, red maple seed production continues. However the young seedlings do not develop beyond the first foliar-leaf stage (McIlveen and Negusanti, 1984; James, 1982) possibly due to a magnesium-calcium imbalance (Contant, 1997).

On the hilltops and freely drained gravely soil, a third transition community (the "Red Oak" community) has developed (Winterhalder, 2002). Current coring shows that many of these red oaks have continued to thrive over the last ten years, with their age extending beyond 40 years on favourable sites.

The ground cover in these transition communities is composed of acid- and fire-tolerant species including lowbush blueberry, sweet fern (*Comptonia peregrina*) and bracken fern (*Pteridium aquilinum*) forming clumps among extensive bare areas (Winterhalder, 2002). Dense moss mats of *Polytrichum commune* and *Pohlia nutans* occupy seepage areas on north-facing slopes and depressions (Winterhalder, 1996).

The moss, protenema (*e.g. Pohlia nutans*), continues to be common on bare soils in this zone, with minor occurrences of filamentous algae on less toxic sites (Winterhalder, 2002). More recently the lichen, *Cladonia rangiferina* and *Parmelia conspersa* have begun to re-establish within this zone (Winterhalder, 2002).

4.3 Natural Recovery Processes

4.3.1 Impediments to Vegetation Re-establishment

Natural recovery of vegetation following the improvement of air quality was impeded in part by the legacy of historic damage attributed to over 100 years of soil degradation. Key limiting factors for recovery, identified by Winterhalder (1995b), include

- loss of soil micro organisms,
- loss of soil organic matter,
- physical loss of soil from erosion,
- needle ice formation that creates soil instability and seedling mortality,
- elevated metal levels in surface soils,
- reduced root development leading to reduced drought tolerance,
- insects and disease,
- soil chemistry limitations,
- severe microclimatic conditions, and
- loss of seed sources.

These factors are discussed in more detail below and were investigated at a variety of well characterized test plots during the ERA field studies (refer to Volume III, Objective 1). .

Metals

A distinct pattern of elevated soil copper and nickel levels closer to the smelters has been documented both in this study and previously by a number of other researchers (McIlveen, 1990; Taylor and Crowder, 1983a&b; Cox, 1975; Winterhalder, 1975; Dreisinger and McGovern, 1969). Average copper levels of "normal forest soils" collected outside of the influence of the smelters range from 15 to 40 µg/g (mean 20 µg/g Cu) (Aubert and Pinta, 1977). However, Hazlett *et al.* (1983) found copper levels up to 9700 µg/g 0.4 km away from the Coniston smelter and Freedman and Hutchinson (1980a) reported levels of 3700 µg/g in organic layers three km away from the Falconbridge smelter. Available copper levels of 300 to 900 µg/g were reported by Rochon (1988), far exceeding thresholds for plants displaying phytotoxic symptoms, which can occur at levels of bioavailable copper between 25 and 50 µg/g (Winterhalder 2002). Adamo *et al*. (1996) also showed that copper is more mobile in acidic soils than nickel because copper is associated with organic matter whereas the nickel is largely present in the form of sulphides or oxides.

Average nickel levels in temperate forest soils range from 20 to 30 µg/g (Winterhalder, 2002). Hazlett *et al.* (1983) reported levels as high as 6,960 µg/g in a soil 0.2 km away from the Coniston smelter and Freedman and Hutchinson (1980) reported levels of 3000 µg/g nickel in surface soils. Rutherford and Bray (1979) found the highest levels of copper and nickel occurred in small depressions in ridge top positions and in surface soils of depressions. Poorly drained soils also showed highest levels of available (pH 3 NH_4OAac extractable) copper and nickel (Winterhalder, 1996; Rutherford and Bray, 1979).

Some studies during the past ten years (Sargent, 1996; Dudka *et al*., 1995; Negusanti, 1995; Gundermann and Hutchinson, 1993) show declining copper and nickel levels in the soil and decreasing bioavailability and phytotoxicity (Sargent, 1996; Gundermann and Hutchinson, 1993), perhaps due to acid leaching and increased rate of organic matter mineralization as soil pH is ameliorated (Winterhalder, 1996). Paleolimnological studies by Dixit *et al*. (1992) near the Coniston smelter indicated that nickel inputs increased from the 1920s to a peak in the 1960s, then declined after the smelter closed in the 1970s.

Elevated metal levels close to the smelters, in both vegetation and soils, were reported by McGovern and Balsillie (1975; 1973), and by McIlveen and Balsillie (1978; MOE, 1982). This pattern was observed from the analysis of samples of wavy hair grass (Hutchinson and Whitby, 1977; Negusanti and McIlveen, 1990), the shrubs sweet fern and lowbush blueberry (Shorthouse and Bagatto, 1995a; Bagatto and Shorthouse, 1991), interrupted fern (*Osmunda claytoniana*) and ostrich fern (*Matteuccia struthiopteris*) (Burns and Parker, 1988), white birch and red maple (Negusanti and McIlveen, 1990; Hutchinson and Whitby, 1977), and in pollution-tolerant lichens *Cladonia deformis* and *Stereocaulon paschale* (Beckett, 1995; Nieboer *et al*., 1972).

Concentrations of copper and nickel in white birch leaves have been reported at levels five times as high as the "upper limits" of normal concentration guidelines in the 1970s (Hutchinson and Whitby, 1977) and two to three times as high by 1987 (Negusanti and McIlveen, 1990). Similar above-average copper concentrations in trembling aspen leaves were reported by Negusanti (1995).

Copper and nickel concentrations in dwarf birch leaves were 10 to 60 times greater closer to the smelters than leaves collected from Manitoulin Island specimens (Rochon, 1988). Similarly, copper and nickel content of cattail (*Typha latifolia*) roots were correlated with soil sediment concentrations. However, foliage levels were not elevated (Taylor and Crowder, 1983b).

Soil Acidity (pH)

Sudbury area soils have been acidified from an expected normal pH range of 4.5 to 5.5 to levels of pH 3.2 to 4.4. Soils collected from hilltops and slopes along a south-southeast transect from Copper Cliff smelters in the early 1970s ranged from pH 3.3 at 2 km distances to pH 3.9 at 34 km distances (Freedman and Hutchinson, 1980b). Titratable acidity was very high (2.5-6 me/100g) with base saturation levels less than 5% (Balsillie *et al*., 1978). Extremes of soil acidity of pH 2.4 (Hazlett *et al*., 1983) and pH 2.2 (Hutchinson and Whitby, 1974) were recorded near the Coniston smelter. Soil samples collected in 1969 from a series of pollution zones showed a mean pH of 4.0 in the heavily polluted zone, around 4.5 in the medium zone and 4.8 in the light zone (Freedman and Hutchinson, 1980a; Dreisinger and McGovern, 1969). However, variability observed in the soils collected within each zone is associated with different parent material, clay or humus content, or degree of erosion (Pitblado and Gallie, 1995). Over the past 20 years, pH levels rose to one unit higher near the Coniston smelter (Sargent, 1996) and have improved throughout the region (Winterhalder, 2002).

Soil Phosphorus

The industrial activities in the Sudbury region have led to losses of total phosphorus because of soil erosion on steep, stony slopes, and decreased organic inputs because of limited vegetation growth. There have also been decreases in phosphorus availability due to increased soil acidity and increased soluble aluminum that interferes with phosphorus uptake and translocation (Winterhalder, 2002). The application of limestone to soils in the region has increased the release of phosphate from inorganic complexation and through enhanced mineralization of organic matter (Fransen, 1991).

Phosphorus is thought to be present in Sudbury soils as phytin (inositol hexaphosphate) and its derivatives from the fossil organic matter added to the soil by the pre-industrial vegetation cover (Winterhalder, 2002). Vesicular-arbuscular mycorrhizae, which facilitate plant uptake of phosphorus, appear to be associated with the successful colonization of plants in the barren and semi-barren sites around Coniston (Blundon, 1976).

Soil Nitrogen

Nitrogen deficiencies are not thought to be the most common limitation to regreening in Sudbury because the soils continue to possess a residual organic component. Once the new vegetation cover has been established, continual additions from vegetative decomposition will be critical to sustaining plant communities. However, well-drained gravel soils in the Skead area continue to show nitrogen deficiency (Winterhalder, 2002). Grasses other than metal- and drought-tolerant native wavy hair grass remain difficult to establish (Winterhalder, 2002).

Algae and cyanobacteria stabilize the soil and can enhance biological nitrogen fixation; however, they are very acid-sensitive (Maxwell, 1995; 1991). The diversity of microflora and faunal populations is very limited in Sudbury soils. Cyanobacteria are absent in untreated areas but colonize barren sites rapidly after liming, probably arriving on the boots of the field staff (Winterhalder, 2002). The native species plant mix of the Sudbury region also excludes nitrogen-fixing Rhizobium-legume associations.

The unicellular alga *Chlamydomonas acidophila* has survived in the soil and has been collected from the Sudbury Barrens (Maxwell, 1995; 1991). The actinorhizal shrub sweet fern, a nitrogen fixer of dry upland sites, is present in both the barrens and the less disturbed jack pine forested areas outside the barren zone. This species has historically played a role in jack pine succession in the boreal forest and may play a significant role in revegetation, especially on sandy soils. Residual populations of sweet fern occur in the uplands and on the barrens and spread rapidly following liming (Winterhalder, 2002). In contrast, the native actinorrhizal speckled alder (*Alnus rugosa*) and green alder (*A. crispa*) show no pattern of expansion following liming. Residual populations occur adjacent to streams and selected wetlands and in the fringes of the industrially damaged lands (Winterhalder, 2002).

Soil Physical Characteristics

The average rate of bedrock weathering in the Sudbury area (50–170 m^3/km^2/year) is similar to other areas with similar climates (Pearce, 1976a). The rate of soil erosion near Coniston (60,000 m^3/km^2/year), however, is double that of comparable vegetated areas. Rates are highest in late August, September and October and late spring (Pearce, 1976a).

Much of the Sudbury rim consists of shallow-soiled bedrock ridges and knobs. The easily eroded silty soils on these ridges were rapidly washed down-slope once the surface vegetation cover died, exposing bedrock surfaces on the hillcrests (Figure 4-8). Few suitable germination sites remained, limited to the bedrock fissures and shallow, drought-susceptible organic and soil deposits trapped in bedrock depressions. In deeper-soiled areas the silty clay deposits became fully eroded badlands once the surface vegetation died or was removed, creating an unstable surface for vegetation recolonization (Winterhalder, 1996).

Figure 4-8 Soil erosion/black bedrock at Martindale Road, Sudbury (photo credit Keith Winterhalder)

Pohlia moss protonemata blankets large surface areas of Sudbury's barren soil and plays a major role in reducing surface soil erosion (Winterhalder, 1996). With improved air quality and the regreening treatments, other plant species have helped to stabilize the soils and limit future soil losses from crest and slope positions.

The silt-rich soils that are so common in the Sudbury basin are also very susceptible to needle-ice formation, which reduces the success of seedling survival. The upper soil layers freeze during the fall on clear nights. The ice that is formed vertically displaces the soil, creating needles that toss out young seedlings and shear off roots, thereby stunting young saplings that have established (Courtin, 1994).

Microclimate

Surface wind velocities and diurnal fluctuations in surface temperatures increase dramatically as vegetation cover is removed (Courtin, 1995). Temperatures taken in the barrens and in the semi-barren open oak woodlands near Falconbridge and Coniston as part of a 1969 to 1970 microclimate study exceeded the thermal death temperatures (47°C) on several days in early summer (Winterhalder, 1996).

Courtin (1994) reported surface soil temperatures in the barrens as high as 70°C. High temperatures and high wind velocities increase drought stress and severely limit the successful establishment and early survival of shallow-rooted young seedlings.

Courtin (1995) suggests that microclimate effects limit the speed of recolonization of vegetation into the barrens. Frost action is extreme on bare soils, and any surface plant litter is rapidly blown off the site. It is only reduced following the establishment of a closed canopy, or a continuous ground cover and when a network of roots develops to bind the soil.

Soil Microorganisms

Soil microbiota play an important role in both nutrient cycling and uptake and therefore influence growth and survival of many plant species. Research has shown that soils within the zone of influence from the smelters are largely devoid of the common suite of soil microorganisms found in temperate forest soils (Winterhalder, 1996). The algal flora of the acid, metal-contaminated soils of Sudbury is characterized by a low diversity of chlorophytes, one or two diatom species and an absence of cyanobacteria (Maxwell, 1995; 1991). The reduced microflora and faunal populations have limited natural revegetation processes (Maxwell, 1995; Winterhalder, 1996).

Copper-tolerant strains of the acid-tolerant chlorophytes *Chlamydomonas acidophila* (Twiss, 1990) and *Chlorella saccharophila* (Hutchinson *et al.,* 1981), and samples of free-living Azobacter-like bacterium have been collected from Sudbury soils. This latter species is capable of fixing nitrogen, however no evidence has been found that this activity occurs under the current soil conditions in the Sudbury Region (Winterhalder, 1996).

It is expected that the single acid- and metal-tolerant bacterium (*i.e.* genus *Azospirillum*) associated with the roots of metal tolerant *Deschampsia caespitosa* is a nitrogen fixer (Hubbell and Haskins, 1984; Winterhalder, 1996). This bacterium is uncommon in the region but has been reported in the Coniston Valley (Maxwell, 1995). It is possible that retaining pockets of metal tolerant strains may be an important future objective of the regreening program to ensure a continued viable seed source for future reclamation of metal contaminated sites.

Daft and Hacskaylo (1976) indicated that vesicular–arbuscular (V-A) mycorrhizal associations (especially in combination with rhizobial associations) accelerate the rehabilitation of industrial wastelands by facilitating successful plant recolonization. They play an important role in the phosphorus cycle partly through their effect on soil particle aggregation. V-A mycorrhizal fungi are almost universally associated with wavy hair grass (Blundon, 1976), oxeye daisy (*Chrysanthemum leucanthemum*), and orange hawkweed (*Hieracium aurantiacum*). These species have successfully recolonized the barrens and semi-barrens at sites some distance from the smelters (Balsillie *et al*., 1978). Closer to the historic smelter sites, this soil fungi, bacteria and soil aggregation is greatly reduced (Balsillie *et al*., 1978). Balsille *et al*. (1978) reported reductions of over 20% in soil particle aggregation greater than 0.05 mm close to the Sudbury area smelters. This corresponded to areas where no plants (and, therefore no V-A mycorrhizae) were present.

Ectotrophic mycorrhizae have been shown to play an important role in the survival and colonization of woody species on the barrens. Jones and Hutchinson (1986) have shown that seedlings infected with *Scleroderma flavidum* grow better than those infected with 3 species of *Laccaria* or those without any mycorrhizae associations in nickel-enriched soils. *Scleroderma flavidum* suppresses the transport of nickel up into the stems with increased effectiveness in phosphorus-rich soils (Jones and Hutchinson, 1988; Jones *et al*. 1986). Growth of mycorrhizal birch seedlings exposed to high levels of copper (63 mm) was also significantly less than that of nonmycorrhizal seedlings (Jones and Hutchinson, 1986).

The role of micoorganisms is often complex. Jack pine seedlings infected with *Rhizopogon rubescens* were shown to be more susceptible to aluminum toxicity than control seedlings. In contrast, seedlings inoculated with *Suillus tomentosus* showed improved height growth in soils enriched with calcium (Winterhalder, 1996).

As indicated earlier, the only native symbiotic nitrogen fixing vascular plant surviving in the barrens is the actinorhizal shrub, sweet fern (Winterhalder, 1996). This species is a common soil amender throughout northern Ontario, colonizing many physically disturbed, nutrient-poor sandy sites.

Similar patterns of reduced mite populations in acid, metal contaminated soils of the Sudbury region have been documented by Winterhalder (1996). Only three oribatid mite species have been collected from barren soils and 33 species on semi-barren woodlands. This number is far fewer than in undisturbed Ontario forests.

Seed Availability

It is commonly understood that biodiversity is one of the critical components of the integrity of natural ecosystems (Rapport, 1989). The major sources of new plant species on the Sudbury barrens are seeds and spores (Winterhalder, 1996). Species with lighter, wind-dispersed seeds and seed-bearing residuals contribute to the early reestablishment of a more diverse plant community. The germination and survival capability of those species on the metal-enriched soils is also important. Red maple, with its heavier samaras, is largely metal intolerant so although more residual individuals are present, maple contributes less to the "new plant communities" than the more tolerant white birch with its rain of very light seeds (Winterhalder, 1996). White birch, trembling aspen, and willows have light, wind-dispersed seeds, with sufficient tolerance to establish on grassed sites (Winterhalder, 1996). The bird-dispersed heavier seeds of the blueberry also readily colonize the limed land, as well as more recently unlimed, naturally recovering lands under the improved air quality environment (Winterhalder, 1996). Occasionally red pine and white pine have also seeded in some distance from the nearest seed source.

Even though there may be a small residual seed bank on the Sudbury barrens, it is not thought to contribute significantly to the reestablishment of vegetation (Winterhalder, 1996).

4.3.2 Natural Recovery: Summary of Current Vegetation

Recovery of vegetation and soil dynamics followed the reduction in atmospheric emissions. Recovery has been slow and limited to specific sites, because soil properties are more critical than air quality in suppressing colonization of the barrens (Winterhalder, 1996). Recovery began on moist, sheltered, nutrient-enriched sites, such as stream channels.

The pattern of plant establishment within the region has followed a noticeable trend. Many of the plants discussed below that have successfully colonized the acidic metal-enriched soils of the Sudbury barrens represent strains with enhanced metal tolerance. Colonization by plants showing genetically based tolerance was reported by Freedman and Hutchinson (1980a). McNeilly (1987) provides a detailed discussion of the implications of genetic selection.

On semi-barren sites, one to several fumigations during a season and root shearing by needle ice formation in the silt-rich soils stunted tree growth well into the mid-1970s. Improved growth measured since 1972, in moderately affected zones, was the result of improved atmospheric quality. Residual woody plants on the barrens have maintained or increased in height growth and vigour over the past 20 years. A more detailed discussion of the recovery by woody species is presented in the following section.

Species Summary:

Lichens

One of the early indications of natural vegetation recovery was the growth of arboreal lichens on the bark of residual balsam poplar (*Populus balsamifera*) in the Sudbury area in 1968 (LeBlanc *et al*., 1972), 1978 and 1989-90 (Beckett, 1995; 1986). These studies show that lichen were invading the formerly lichen-free zone around the (now closed) smelters, colonizing the rocks, soils, and less commonly tree bark. The less pollution-tolerant *Cladina rangiferina* and *Cladina mitis*, characteristic of boreal forest understory, were slower to recover, and in the early 1990s were common only in the peripheral areas beyond 20 km from the historic smelter locations (Cox, 1993). The occurrence and abundance of lichen are greatly reduced in close proximity to the smelter sites.

Tickle grass and sheep sorrel

The metal tolerant, short-lived perennial, tickle grass (*Agrostis scabra*), and acid tolerant sheep sorrel (*Rumex acetosella*) were among the first species to recolonize the barrens between 1967 and 1987 (Winterhalder, 2002). Tickle grass also invaded early experimental plots (established in 1972 under the Sudbury Environmental Enhancement Program). It was successful in invading unlimed but fertilized (nitrogen-phosphorus-potassium) sandy soils in the Coniston Creek Valley (Winterhalder, 2002). In contrast, agricultural grasses were unable to successfully germinate on these toxic soils.

Tickle grass continues to expand into the barrens and transition forests from populations that first established along roadsides, in the flood plains of creeks, under residual white birch, *Populus* sp. and lowbush blueberry where the soils were enriched with organic matter, and in rock crevices on patches of metal tolerant *Pohlia nutans* (Archambault and Winterhalder, 1995; Beckett, 1986).

Tufted hair grass

Tufted hair grass (*Deschampsia caespitosa*), a multiple metal tolerant native grass species (Cox and Hutchinson, 1980), was first detected in the barrens in the early 1970s in moist depressions (Cox and Hutchinson, 1980). It created the ground cover in the trembling aspen savannah-like woodlands in the Coniston Creek Valley (Winterhalder, 2002).

The origin of these populations is unknown, although genetically distinct but similarly metal tolerant populations of tufted hair grass occur 80 km southwest of Sudbury (Goat Island Coal terminal on the North Channel) and in Cobalt, 150 km northeast of Sudbury.

Canada bluegrass, red-top, foxtail barley

Red-top (*Agrostis gigantea*) and Canada bluegrass (*Poa compressa*), two introduced grasses with enhanced copper and nickel tolerance, have also colonized the barrens, spreading from populations that are thought to pre-date the revegetation program (Hogan and Rauser, 1979; Hogan *et al*., 1977). These species are also used in the regreening program (Winterhalder, 2002) because they thrive on heavier silty clay soils.

Canada bluegrass successfully colonizes the sides of deep gully-eroded silty clay barrens (Cox and Hutchinson, 1980; Winterhalder, 1996). In contrast, red-top grass occupies the base of eroded gullies (Cox and Hutchinson, 1980). Hogan *et al*. (1977) and Hogan and Rauser (1979) found copper- and nickel-tolerant strains of red-top on the copper- and nickel-rich surface of the old O'Donnell roast bed. Winterhalder (1984) reported enhanced zinc-tolerant bluegrass. The introduced grass, foxtail barley (*Hordeum jubatum*—an invasive) also colonized the roast beds but was not metal-tolerant; rather, it invaded as pH rose with the increased calcium content of this section of the roast bed surface.

Wavy hair grass

The acid-tolerant native wavy hairgrass is the dominant grass species in the fume-modified area near the former iron smelter at Wawa and colonizes the Coniston barrens (Winterhalder, 2002). Wavy hair grass is also a common understory in white birch or red oak dominated semi-barren woodlands (Winterhalder, 1996), and although it was not reported by Gorham and Gordon (1960a,b), it is a recent colonizer in the Sudbury area. Its well-known tolerance of low pH (Larcher, 1975) and high soluble aluminum allowed its spread following the improvement of air quality (Winterhalder, 1996).

Poverty oat-grass and white-grained mountain-ricegrass

Poverty oat-grass and white-grained mountain-ricegrass (*Oryzopsis asperifolia*) are less common in the barrens areas, although populations have been reported northeast of the Falconbridge smelter (Winterhalder, 1996).

Sedge, field horsetail and woodland horsetail

A sedge species, likely *Carex foena* (*aenea*) (bronzy sedge or broom sedge, referred to by Freedman and Hutchinson 1980b as *Carex praticola* from the group Ovales) invaded the drier lowland barren soils and occasionally colonized the rocky slopes. Woodland horsetail (*Equisetum sylvaticum*) and field horsetail (*E. arvense*) have also survived on the silty-soiled barrens.

Wool-grass, retrorse sedge, pointed broom sedge, willows

Pointed broom sedge (*Carex scoparia*) has successfully colonized moister sites in the Barrens and Transition Forests, occupying both silty clay soils and acidic (pH as low as 3.8), metal rich (200 mg/kg Cu, 100 mg/kg Ni) rocky tills (Reid, 2000). Retrorse sedge (*Carex retrorsa*), wool-grass (*Scirpus cyperinus*), balsam willow (*Salix pyrifolia*), upland willow (*S. humilis*), slender willow (*S. gracilis)* and shining willow (*S. lucida*) have also colonized the transition forests (Winterhalder, 2002).

Narrow-panicled rush, manna-grass

Other species that have colonized metal contaminated barren organic soils and seepage zones since the 1970s include narrow-panicled rush (*Juncus brevicaudatus*) and Canada manna-grass (*Glyceria canadensis*) (Winterhalder, 2002).

On metal contaminated organic barrens, narrow-panicled rush, Canada manna-grass and tickle grass commonly form communities (Winterhalder, 1996). In 1974, a wetland 4.5 km NW of the Coniston smelter was barren with cattail growing in the lag area and a narrow band forming concentric circles of Canada manna-grass (Winterhalder, 1996). By 1993, narrow-panicled grass, tickle grass, wool-grass and Canada manna-grass had completely colonized the previously barren centre (Winterhalder, 1996).

Cattails

Cattails are common in highly contaminated marshes (Taylor and Crowder, 1984; McNaughton *et al*., 1974). Field grown plants were able to exclude the metals, possibly by formation of a ferric iron plaque at the root surface (Taylor and Crowder, 1983b).

Dwarf birch

The metal tolerant strain of dwarf birch (*Betula pumila*) colonized the vegetation-poor, upland tills adjacent to a small fen in the early 1980s (Winterhalder, 2002; Rochon, 1988).

Residual islands of herbaceous species

Herbaceous species often occur as small residual islands (Figure 4-9). Of note are patches of sweet fern, bracken fern, club-moss (*Lycopodium* sp.), trailing arbutus (*Epigea repens*), and wintergreen (*Gaultheria procumbens*). On the sandier barrens (near the airport), distinctive linear clones of running pine (*Lycopodium clavatum*) form a barrier between clumps of white birch and trembling aspen and the bare wind-blown sands.

Figure 4-9 "Island" effect of herbaceous plant growth on barrens

Residual woody species: Red oak, red maple, white birch and trembling aspen

Red oak, red maple, white birch and trembling aspen are the most common tree residuals (Winterhalder, 1996), with very widely scattered individual yellow birch (*Betula allegheniensis*) residuals growing in seepage zones on hill slopes. Trembling aspen's ability to form root suckers has led to clonal patches on lowland sites that rarely display foliar symptoms of stress. They produce copious seeds but germination is not successful except on limed soils (Winterhalder, 1996). In contrast, white birch and red oak have successfully established in both untreated and treated sites. Scattered residual conifers (red pine, jack pine, white pine, black spruce, white spruce, balsam fir and eastern white cedar) are also found throughout the region, providing a limited natural source of conifer seed. Each species is briefly discussed below.

White Birch:

On the barrens and semi-barren transition forest areas, white birch (Figure 4-10), a species with no apparent genetic-based metal tolerance, is slowly colonizing from seeds produced by residual populations. Winterhalder (1996) hypothesizes that successful expansion of this species is a result of phenotypic plasticity. Recent studies identified that radial growth of white birch was reduced within a 20 km radius of the smelters during the mid 1960s to 1970s (Marshall *et al.*, 2005b). However, after 1978, growth of birch within this radius was comparable to growth rate of birch from a reference site. Recovery of tree growth closer to the smelters was attributed to reductions in SO_2 emissions. In contrast, barrens colonization by trembling aspen is rare.

White birch residuals occur as coppiced individuals displaying mid-season marginal chlorosis (Winterhalder, 1996) attributed to:

- Low soil magnesium and/or calcium, creating a direct nutrient deficiency or reduced protective role of bases against metal toxicity or a calcium-magnesium imbalance;
- Moisture, and/or nutrient deficiency as a result of reduced and physiological impaired root systems because of metal toxicity;
- Root damage caused by low temperatures due to a lack of insulation from leaf litter and snow cover;
- Diminished cycle of stored photosynthate (McIlveen and Negusanti, 1984); or,
- Moisture stress in early spring when soils remain cold but air temperatures in these open sites can rise to trigger growth.

Regeneration is primarily by coppice regrowth. However, seed germination is occasionally successful, especially near the inactive Coniston smelter (Winterhalder, 2002). White birch weakened by metal toxicity and resultant physiological drought is also susceptible to bronze birch borer (*Agrilus anxius*) infestations, which reduce growth and can lead to mortality.

Figure 4-10 White birch and pine

Red Maple: Residual red maple display foliar symptoms of stress in the form of premature reddening (Winterhalder, 1996). Coppiced individuals display progressive regressive dieback that leads to reduced leaf biomass and mortality of stems surrounding the stool. Ultimately all meristematic sites for suckering are used up and the individual dies. Seed production can be high but seedlings redden and rarely progress beyond the first foliar leaf stage (Winterhalder, 1996). Magnesium deficiency or magnesium calcium imbalance or a lack of V-A mycorrhizal infection may be the cause (Winterhalder, 1996).

Red Oak: Red oak acorns successfully germinate beneath existing oak stands but are less common to absent on the barrens, perhaps due to their large seed size and the absence of dispersal into the barrens by squirrels and other rodents (Winterhalder, 2002). It is, however, successfully transplanted as part of the Sudbury Land Reclamation Program.

Jack pine, red pine, white pine, white spruce: These conifers require mineral soil or decomposed organic matter to successfully germinate. However, toxicity of the surface mineral soils of the Sudbury Region limits germination success except in limed areas. Pine and spruce have successfully colonized the less toxic rock crevices where recent foliation and weathering has created pockets of soil and seepage zones (Winterhalder, 1996). In the past, the limiting factor may have been the absence of mature seed sources. It is thought that the relatively large winged seeds are carried considerable distances by wind drift over the hard packed winter snow surfaces similar to the distribution of yellow birch seed (Winterhalder, 1996). The success of the tree-planting program in the region has led to the establishment of young local seed sources that are 15 to 30 years old. Red pine and jack pine have established along major road corridors and at select locations throughout the transition forests. White pine, with its intolerance to poor air quality, is less common than the hardier red pine and jack pine.

Residual Shrubs

Residual shrubs in the barrens are often represented by small patches. Red-berried elder, northern wild-raisin, and willow occasionally occur as individual clumps on the barrens however there is no evidence they are spreading by seed (Winterhalder, 1996). Lowbush blueberry is a common residual shrub species of the barrens (Figure 4-11), and is discussed below.

Lowbush Blueberry: It is highly acid- and fire-tolerant, capable of expansions from its extensive rhizome system (Hall *et al*., 1979). It expands into untreated barren soils that show reduced toxicity due to leaching, erosion or reduced smelter impact (Winterhalder, 1996). Lowbush blueberry proliferates rapidly once an organic layer is formed (Trevett, 1956) and continues to increase in abundance in areas where the birch canopy remains open (Winterhalder, 1996). Frequent light ground fires stimulate regrowth and minimize competition from more shade tolerant species.

Figure 4-11 Blueberry

4.4 History of Regreening Practices and Programs

4.4.1 Triggers for Regreening the Industrial Landscape

The rapid modernization of mining processes approximately 25 years ago led to major reductions in labour requirements for extraction and processing, resulting in the layoff of up to 3,500 employees (Lautenbach, 1985). The negative image of the industrial landscape made it difficult for Sudbury to attract new businesses to provide alternate employment and create economic diversification to sustain a viable city.

At the same time, more stringent government emission guidelines were put in place in the early 1970s following the passage of the provincial Air Pollution Act in 1967. The Ontario Ministry of the Environment introduced improved air quality standards that restricted both particulate and sulphur dioxide emissions, and reduced the number of local air emission sources.

The mining industry concurrently invested in a number of improved technologies to reduce air emissions, the most significant of which was Inco's construction of a tall (380 m) superstack in 1972 to disperse emissions over a wider area to reduce local emission concentrations (Bouillon, 1995). A more complete description of historical air emissions is provided in Chapter 3.0.

Improved air quality, more stringent environmental guidelines, a healthy mining economy, and a major reduction in mining-related employment in Sudbury led ecologists in the Sudbury area to believe that regreening efforts could succeed and that funds could be leveraged from various industrial and government sources to carry out regreening activities.

4.4.2 Overview of Regreening Efforts: 1917 Onward

Early Goals of Community-Led Program

The community-led program for the regreening of Sudbury was initiated more than 30 years ago. A review of past programs indicates that regreening efforts were primarily designed to do the following:

- Reduce dust;
- Add colour to the blackened landscape by establishing a conifer and mixed hardwood tree cover;
- Provide employment;
- Improve the image of the community to attract new businesses and investment; and,
- Provide areas for recreation.

Topsoil Replacement: Reclaimed Parks

Early efforts at recovery were directed towards controlling dust clouds that originated on dry tailings and permeated throughout the homes of people who lived close to the tailing areas in Copper Cliff and Falconbridge. In 1917, efforts were made to reclaim an abandoned roast bed at Nickel Park in Copper Cliff (Chislett, 1983). A similar park (Centennial Park) was created in Falconbridge on an old tailings deposit (Winterhalder, 2002; Lautenbach, 1985). Less acidic and less metal-toxic soils were imported and sites were landscaped using traditional gardening methods. This also occurred in selected locations in Sudbury, such as small city parks. Berms mantled with imported soil were created along Highway 17 by Vale Inco. These very labour-intensive methods and heavy financial investments were deemed feasible only in very small areas.

Initial Tree-Planting Attempts: 1969-1970

A traditional tree-planting program, following the approach used by the Department of Lands and Forests on cutovers, characterized the first widespread regreening efforts. The Department of Lands and Forests provided funding and trees for the early tree-planting program. Several thousand trees were planted in 1969 and 1970, largely in traditional rows. However, the majority of the trees planted in barren areas during these early years died (Winterhalder, 1983a).

Technical advice was then sought from Inco's agriculturalists, Tom Peters and Clare Young, who had successfully implemented a seeding and legume establishment program on their tailings. Biologist Bob Michelutti of Falconbridge provided additional technical advice. These programs were evaluated and modified by Keith Winterhalder to develop an effective program for regreening steeper rocky hillsides where the agricultural methods of applying limestone, fertilizer and grass using farm machinery were not feasible. Winterhalder's experiments showed that germination and growth of native plants such as grasses, birch, poplars and willow were enhanced by the simple application of lime to the surface soils. His studies showed that calcium reduced toxicity by competing with toxic metals (aluminum, copper and nickel) for entry into the roots, and strengthened the membranes that control movement of nutrients and toxins into root cells. The carbonate also neutralized the soil and converted metals to less toxic forms (Winterhalder, 1983b).

These programs are further described in the following sections.

Agricultural-Type Areas on Tailings and Flat Land: Tilled Areas

In the 1950s, University of Guelph agricultural graduate, Tom Peters (Inco Ltd), and Clare Young applied traditional agricultural techniques of tilling and soil amendment, followed by direct seeding (of grass) on tailings. They then supervised the application of these methods on adjacent level, accessible, barren soil areas and abandoned fields owned by the mining companies (Lautenbach, 1985; Chislett, 1983). Peters also supervised the contouring of rocky slopes with bulldozers, followed by tillage and seeding in a nurse crop with agricultural machinery (Peters, 1995; 1978).

Bob Michelutti (Falconbridge Ltd.) carried out similar seeding activities in the 1970s on prepared lands in the Falconbridge area. Prior to this, Thomas Lloyd of Falconbridge Ltd. planted the pollution-tolerant hybrid Carolina poplar (*Populus* x *canadensis*) in large planting holes filled with imported nutrient rich black loam soils at the entrance of Falconbridge (Winterhalder, 2002). These trees have survived past fumigations and continue to thrive as mature trees at the entrance to the town.

Early Experiments: Test Plots on Stony and Hilly Terrain

Early trials were established in 1969 on shallow-soiled steeper sloped terrain, where the agricultural methods were not feasible, under the direction of Sudbury Environmental Enhancement Programme (SEEP) (Winterhalder, 2002; Lautenbach, 1985) (see Section 4.6.1).

Extensive sampling and testing of soils from the barrens and semi-barren areas was conducted in 1969 and 1970 to determine the ability of the soils to support growth. Several thousand bare root nursery stock trees (29 native and exotic species) were planted near Coniston and Skead. Agricultural seed mixtures of grasses and legumes were sown (Lautenbach, 1985). Tree seedling mortality near Coniston was 100%; survival at Skead was high but growth was poor (McHale *et al.,* 1974). This led to further testing under controlled greenhouse experiments and field trials to determine the factors limiting survival and growth. These experiments identified low pH, low nutrient levels, and elevated copper and nickel levels as limiting factors (Lautenbach, 1985; Balsillie *et al.,* 1978; Hutchinson and Whitby, 1974; Winterhalder, 1974). Soil acidity and toxicity limited root growth, which often led to mortality from drought. The experiments also demonstrated that survival increased with the application of lime and fertilizer amendments. These amendments enhanced root growth, reducing seedling susceptibility to drought (Winterhalder, 2002; 1978; Hutchinson and Whitby, 1977). Subsequent plantation trials were established by the Ontario Ministry of Natural Resources in 1976 to test the effectiveness of using Japanese paper pot jack pine and red pine seedlings as compared to bare root stock on limed and fertilized soils at Skead and Coniston (Negusanti, 1978).

In 1974 and 1975 approximately 2.4 ha along the Garson-Coniston Road and 5.6 ha of the Sudbury Airport outfield were grassed with Canada bluegrass and red-top (Chislett, 1983). Subsequent studies indicated that soils of low pH with elevated copper and nickel limited germination and early growth of red-top, one of the key grasses used for revegetation (Winterhalder, 2002). Experiments showed that the interaction between nickel and copper increased toxicity and dramatically reduced root growth. Studies also showed that aluminum seemed to “protect” plants from high nickel concentrations (Winterhalder, 1983b). Liming raised pH sufficiently to reduce soil toxicity, facilitating growth and survival of grasses on many sites (Winterhalder, 2002).

Winterhalder established additional experimental plots in 1974 and 1975 under the Regional Forest Inventory Student Team (FIST) program. These plots were situated on steeply sloped terrain and organic terrain along the railway and highway arteries into the region (Winterhalder, 1975). He was able to successfully establish standard agricultural grass mixtures on steeply sloped terraced, limed, and fertilized sites without site preparation. These methods were then applied by elementary students at two local schools (Winterhalder, 2002). Although frost heaving continued to occur on these silty loam soils, enhanced root growth following liming reduced mortality (Winterhalder, 2002; Sahi, 1983). Liming also reduced metal toxicity and increased microflora and fauna which further enhanced growth. Native woody species quickly invaded these treated sites (Winterhalder, 1984; Negusanti, 1978).

In contrast, less success was met on the silty clay "badlands" near Coniston where surface liming and seeding was ineffective. On these sites, early trials were set up to establish the non-native tree species, black locust (*Robinia pseudo-acacia*) (Winterhalder, 2002).

Inco and Falconbridge: Early Efforts

Early regreening efforts were initiated and delivered by Inco Ltd. in the 1950s under the direction of agronomist Tom Peters. In the early years, Inco Ltd. created and landscaped berms along Highway 17 using imported soil (Lautenbach, 1985). Inco agronomists pioneered restoration programs using agricultural approaches of tilling, liming and seeding at Inco Ltd. in the 1960s onwards, as discussed above (Lautenbach, 1985; Peters, 1970; 1978). By the mid-1980s more than 1,640 ha of tailings and sand pits owned by Inco Ltd. had been reclaimed using these methods (Lautenbach, 1985). Similar treatments were applied by Falconbridge close to their operations.

Small annual tree planting operations were carried out by Inco Ltd. in the early 1960s, with a total of 130,000 seedlings planted in the first five years (Lautenbach, 1985). Falconbridge Ltd., as early as the late 1950s, also implemented a tree-planting program, although success was restricted to areas where imported loam soil was placed in the planting holes. Over 250,000 Carolina poplar (*Populus* x *canadensis*) (10,000 trees per year) were planted between the late 1950s through to the late 1970s (Lautenbach, 1985). Well-established poplars now mark the entrance to the community of Falconbridge.

In the late 1970s and early 1980s, efforts by both the municipality and the mining companies were directed towards manually applying lime to detoxify soils, grassing to rapidly regreen the landscape, and establishing a tree cover along the major access routes into the City of Sudbury and in local parks, neighbourhoods, and lands adjacent to schools (Winterhalder, 1996).

During this period efforts were also directed towards removing visual evidence of historic damage to the vegetation. As such, stumps and standing snags on sites adjacent to major roads were extracted, piled, carried away from the site, burned, or moved away from view along the access roads (Lautenbach, 1985). These sites were then limed to reduce soil toxicity and planted with conifer seedlings.

4.4.3 The Region of Sudbury Land Reclamation Program

In 1977, the regional council, through its Regional Plan, officially set out a program to enhance the region's visual quality through the reclamation of disturbed lands (Lautenbach, 1985). An operational Land Reclamation Program was launched to carry this out. Effective treatments for regreening were known for some site conditions but were not fully understood for all landscapes in the region. The program was designed to have both a large-scale operational program and an experimental component.

More than 4,400 temporary employment positions were created between 1978 and 2005 to accomplish the manual application of lime, fertilizer and seed on barren lands in the Sudbury area, and to carry out complementary reclamation activities under the city's Land Reclamation Program (City of Greater Sudbury, 2005). This program has expanded and ebbed over the years, as funding and the economy dictated. Program funding and administrative details are provided in Section 4.6 below.

The Formula

The operational core of the Land Reclamation Program consists of the following:

- Site improvement;
- Liming;
- Grassing and greening;
- Tree planting;
- Planning and mapping; and,
- Monitoring and assessment.

Site "Improvement"

The first step of treatment in the early years was the removal of "unsightly vegetation debris" along major corridors. Crews removed the dead snags and stumps, and pruned dead limbs to increase the aesthetics of the site. Debris was initially burned and then dragged away from the "viewshed" (Lautenbach, 1985). In recent years, recognition of the benefits of downed woody material has meant that this material is left intact on the site or broken down to ground level and left to reduce soil erosion (Winterhalder, 2002).

Lime Application

Dolomitic limestone is applied at an average rate of eight to ten metric tonnes per ha to reduce soil acidity. The actual rate varies with soil pH and colloid content (Lautenbach, 1985). Over the years, lime was hauled manually or ferried by truck, rail, or helicopter (80 to 140 bags per load) to distribution points where individuals spread the lime (Figure 4-12). Lime bags were placed in a grid pattern at one to two meter spacing to provide a relatively even distribution. The mining companies have helped in recent years with the aerial application of lime.

Figure 4-12 Liming Crew

How Liming Works: The Detoxifier and Trigger Factor

The early work of Winterhalder demonstrated that the application of dolomitic limestone (calcium and magnesium carbonate—CaMg ($(CO_3)_2$) applied to the soil at an average rate of 10 metric tonnes per ha neutralized high soil acidity sufficiently to trigger the natural recovery of plant cover. White birch resprouted from the root collar, a number of metal-tolerant and drought-tolerant plant species spread by vegetative means from small residual populations, or plants germinated from the small existing seed bank or from the larger incoming wind-disseminated seed rain (Winterhalder, 1988b). The application of calcitic limestone did not have the same beneficial results, perhaps because the absence of magnesium in the soil amendment may induce a magnesium deficiency when the calcium: magnesium balance is altered or when levels of aluminum or ammonium ions increase following liming (Schultze and Freer-Smith, 1991). The land area limed annually from 1978 – 2004 is illustrated in Figure 4-13.

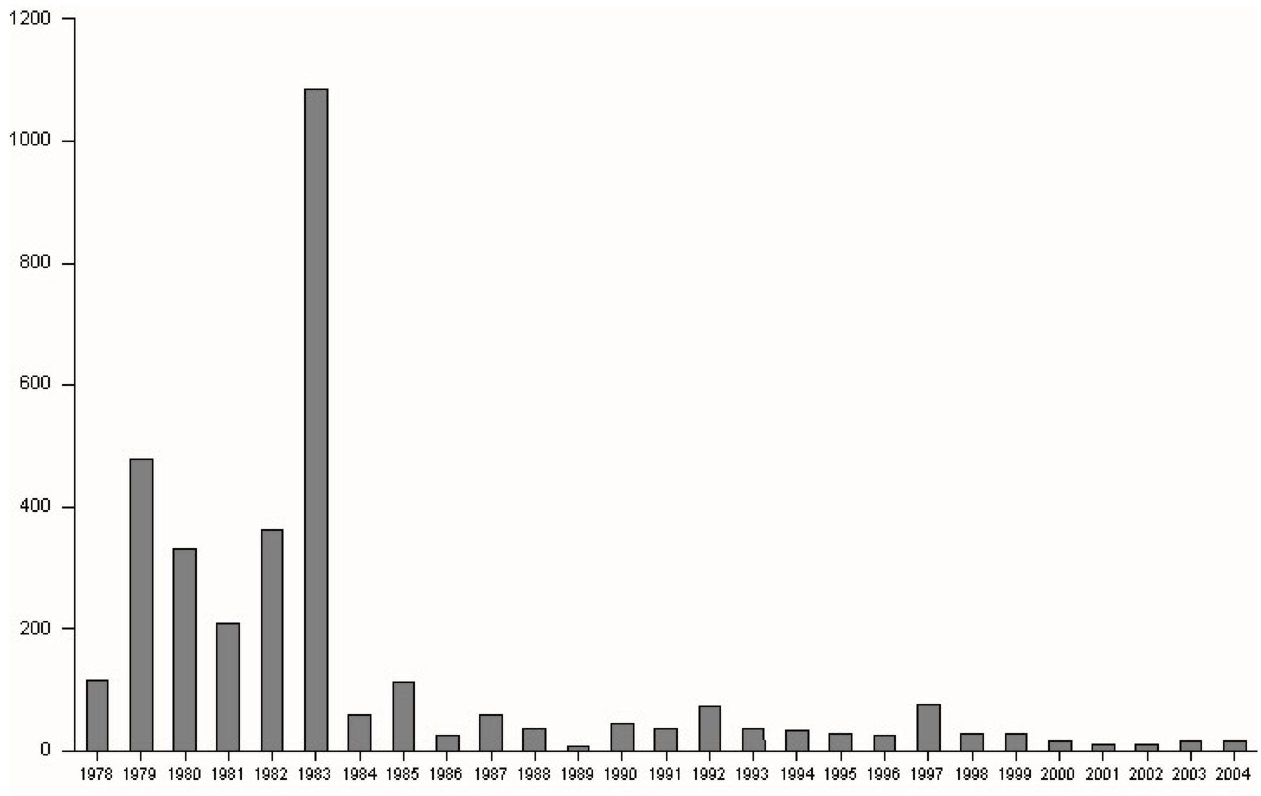


Figure 4-13 Area limed per year (ha), 1978 to 2004

Site-specific lime requirements were initially assessed; however, early test results showed that the liming rate had little effect on the success of the treatment. In many monitored sites, after one year, the soil of successfully treated sites was only one unit higher than adjacent untreated sites. Even this relatively small change in pH was sufficient to trigger natural recovery processes and a second application of lime was found to be unnecessary. For example, the pH of soils at a site located at the Southview Drive - Southwest Bypass junction near Kelly Lake, limed and planted in 1982, has increased by two units over nine years (Winterhalder, 2002). An adjacent untreated site is still dominated by metal-tolerant wavy hair grass.

It is hypothesized that the deeper-rooting poplar and shrubs of the treated site "pumped" up bases from the subsoil and contributed bases in deciduous leaf litter (Winterhalder, 2002). The establishment of pine alone would accentuate the acidification of the soil (Winterhalder, 2002). Therefore, the system adopted by the Sudbury regreening program of planting pines concurrently with the natural recovery of poplar and white birch provided for a natural fertilization system. In addition, the calcium and magnesium in the dolomitic limestone used in the revegetation program play a nutritional role (McHale and Winterhalder, 1997). A secondary hypothesis is that dolomitic limestone may trigger a protective magnesium-nickel antagonism that is absent if calcitic limestone is used.

The hydroxylation of the trivalent aluminum ion as pH increases by liming contributes to detoxification. In addition, Hutchinson and Collins (1978) indicated that calcium and magnesium ions in dolomitic limestone competitively excluded metal ions (*e.g.*, copper) from the root hair's exchange complex and in addition, calcium improved plasma membrane integrity. McHale and Winterhalder (1997) showed the benefits of liming to the growth of red-top and bird's-foot trefoil.

Fertilization

The limed areas are then hand-fertilized (with a manual cyclone seeder) at a rate of approximately 390 kilograms per ha with a fertilizer high in phosphorus (6-24-24) to promote grass germination and growth (Lautenbach, 1985). The fertilizer mix used for site amelioration has evolved over time as shown in Table 4.1. The application of fertilizer has been dramatically reduced during the past ten years and today many areas receive no applications. Fertilizers are applied a few weeks after liming at the same time as seeding.

Table 4.1 Fertilizer Mixtures used in Land Reclamation Program

Year	Fertilizer Type
1978	5-20-20
1979	6-24-24
1980	5-20-20
1981	6-24-24
1982	6-24-24
1983	6-24-24
1984	6-24-24

Seeding

A standard regreening seed mix (five grass species and two legumes) is hand-spread at a rate of 30 to 45 kg per ha (Winterhalder, 1996; Lautenbach, 1985) in late August and September. Fall germination occurs within two or three weeks, allowing early root development prior to winter, except for bird's-foot trefoil (*Lotus corniculatus*) that remains dormant in winter and germinates in the spring (Winterhalder, 1996). The moist fall soils and cooler temperatures increase germination success and survival of the seedlings (Winterhalder, 1996).

Table 4.2 shows the evolution of the seed mixture used in the regreening program. The typical grass-legume mixture, which was largely stabilized in 1983, is identified in Table 4.3.

Table 4.2 Seed mixtures used in the Sudbury Regional Land Reclamation Program (% composition by weight)

		1978	1979	1980	1981	1982	1983	1984
Agrostis gigantea Roth	Redtop	10%	12%	12%	20%	20%	20%	20%
Festuca arundinacea Shreber	Tall fescue	20%	20%	25%	15%	15%	-	-
Festuca rubra L.	Creeping red fescue	-	28%	28%	20%	20%	10%	10%
Phleum pratense L.	Timothy	15%	15%	15%	15%	15%	20%	20%
Poa compressa L.	Canada bluegrass	40%	-	-	15%	-	15%	15%
Poa pratensis L.	Kentucky bluegrass	15%	10%	10%	-	15%	15%	15%
Lotus corniculatus L.	Birdsfoot trefoil	-	5%	-	5%	5%	10%	10%
Trifolium hybridum L.	Alsike clover	10%	-	10%	10%	10%	10%	10%

Source: Lautenbach, 1985

Figure 4-14 Grass growing after being seeded

Table 4.3 Typical seed mixtures used in the Sudbury Regional Land Reclamation Program (% composition by weight)

Agrostis gigantea	Redtop	20%
Festuca rubra	Creeping red fescue	10%
Phleum pratense	Timothy	20%
Poa compressa	Canada bluegrass	15%
Poa pratensis	Kentucky bluegrass	15%
Lotus corniculatus	Birdsfoot trefoil	10%
Trifolium hybridum	Alsike clover	10%

Source: Winterhalder, 2002

Tree Planting

The first major tree-planting program began with 230,000 trees planted on reclaimed lands in 1983. Bare rootstock was planted in the spring of 1983 on lands previously treated with lime and grass seed. Planting of coniferous and hardwood trees (sugar maple, red oak) at low densities occurred on 16 sites. Plantings occurred in clusters to allow for natural infilling.

Historically, the tree species planted by the Land Reclamation Program have been 95% coniferous species and 5% deciduous species. Coniferous species have included jack, red, mugo and white pine, white, black and Norway spruce, Japanese larch, tamarack, and white cedar. Deciduous species have included red oak, silver and sugar maple, black locust, and white ash.

Planting also occurs on unlimed semi-barren transition forest areas (Winterhalder, 2002).

Over 8.5 million trees have been planted to date under the city's Land Reclamation Program (City of Greater Sudbury, 2005). Tree seedling survival is good, calculated as 78% for jack pine, 76% for red pine, and 72% for white pine (Winterhalder, 2002). Growth rates follow a similar pattern with mean annual height growth of 41 cm for jack pine, 33 cm for red pine and 12 cm for white pine. In contrast, black locust grows 50 cm per year (Winterhalder, 2002).

Planting densities have remained relatively low, although with concerns relative to climate change, consideration has been given to increasing the densities to forestry rates. This would increase the rate of carbon dioxide fixation from the atmosphere to 100 tonnes of carbon sequestered per ha over a 30-year period (Beckett *et al*., 1995).

Plantings continue to be primarily red pine and jack pine, reflecting the greater sensitivity of white pine to SO_2 fumigations even though the improved air quality has virtually eliminated leaf damage from fumigations. Red oak continues to be the most successfully planted native deciduous tree, grown together with yellow birch from local seed. Small numbers of yellow birch have been planted on sheltered, moist, silty-clay sites (Winterhalder, 1996b).

Many of the wooded communities have been left to regenerate without intervention (Winterhalder, 1996). Courtin (1994) indicates that human intervention is required in the birch transition community to bring about canopy closure and increase biodiversity and a range of tree species should be planted rather than ameliorating the soil. McCall *et al.* (1995) showed by comparing 1970 and 1989 air photographs that 22% of semi-barren or birch transition woodland was recolonized by conifers.

Figure 4-15 Planting pine seedlings

Program Results

Nearly 3,400 ha of barren lands have been limed (most of which was also fertilized and seeded with grasses/legumes) and nearly 8.5 million tree seedlings were planted between 1978 and 2005 under the city's Land Reclamation Program (City of Greater Sudbury, 2005) (Figure 4-16). Lime continues to be added to portions of watersheds to reduce soil toxicity, to enhance the success of natural recolonization and to improve water quality.

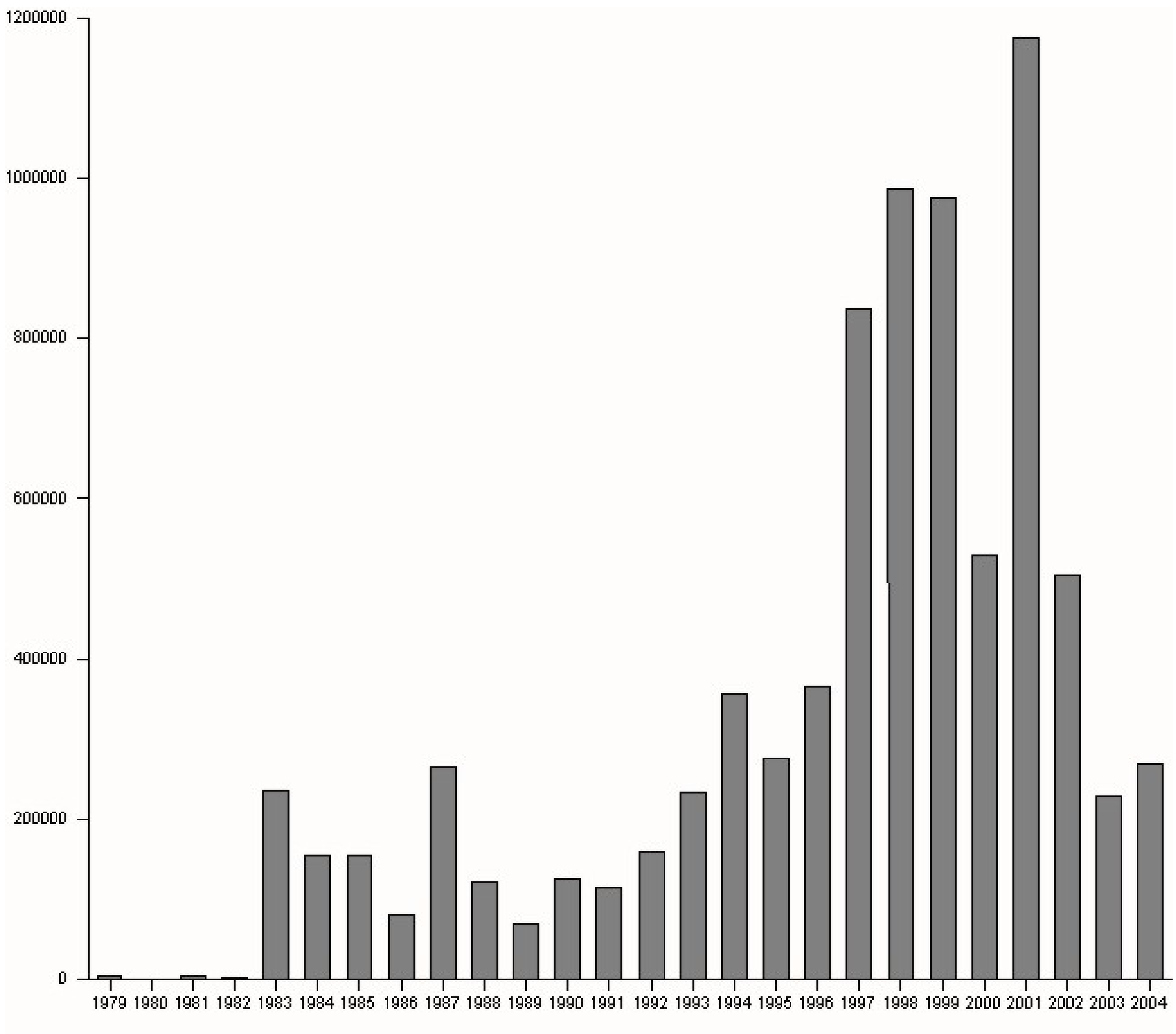


Figure 4-16 Trees planted per year (ha), 1978 to 2004

Between 1975 and 1989 McCall *et al.* (1995) showed a 42% decline in the area classified as barren, and a 28% decrease in the area classified as semi-barren. He attributed this to the reclamation program. However, recent analysis of satellite imagery (see Chapter 5) and a review of the regreening maps suggest that many of these changes can be attributed to the re-establishment of metal-tolerant native species and expansion and growth of native white birch clonal communities.

The success of the Sudbury Land Reclamation Program, as reflected by the reestablishment of a closed conifer cover, is less clear on recent satellite imagery, perhaps due to both the scale of interpretation, which dilutes the success of plantations established in narrow bands and clusters along major access routes, and in part because many of the recently planted sites are still too young to be clearly detected on broad scale satellite imagery.

4.5 Current and Evolving Strategies for Regreening

While the "traditional" regreening strategies of liming, seeding and tree planting continue to be applied, new methods and approaches are continually evolving to meet the changing goals of the regreening program. This section presents new strategies for regreening that have been tested in the region but have not expanded into major operational programs, as well as outlining the programs monitoring the progress of the regreening process.

4.5.1 Recent Goals: Ecological Objectives to Regreening

More recently, ecological objectives have been added to the regreening strategies, with goals to create a landscape that more closely resembles pre-mining forest communities, similar to other provincial policies. For example, the Crown Forest Sustainability Act directs forest management activities to sustain native forests consistent with those that would establish under natural disturbance patterns, and the Parks Act emphasizes the need to protect plants, plant communities, and wildlife that are representative of specific ecological regions.

To achieve these ecological goals, the regreening program plants native species, and is diversifying the species that are seeded and planted to increase biodiversity and to increase the diversity of future seed sources for natural infilling. In addition, more attention is made to matching species plantings to specific landscape positions to provide effective wildlife habitat and to recreate the forest cover that is thought to have occupied the landscape prior to 1900.

4.5.2 Sod Transplants or Soil Plugs

The transplanting of "soil patches" is being tested at a larger scale to explore the operational feasibility of creating small islands of complete plant and soil communities to serve as sources for vegetation colonization into the adjacent barrens. Transplanting blocks of soil and associated plants from natural communities creates nuclei for vegetative spread, introduces a small seed bank from an early stage of plant community development, and provides a source for native soil microbiota (Winterhalder, 1995; 1996; Glass, 1989). Sod transplants have been removed from sites at risk (under hydro lines or in areas where land clearing is occurring). Blocks with typical jack pine understory species such as Canada lily-of-the-valley *(Maianthemum canadense*), bunchberry *(Cornus canadensis*) and wintergreen *(Gaultheria procumbens*) have been successfully transplanted and both persist and are spreading vegetatively (Winterhalder, 2002).

Blocks containing the native actinorrhizal nitrogen fixer, soapberry *(Shepherdia canadensis*), from dolomitic limestone soils in Manitoulin Island have survived, showing evidence of vegetative spread but little evidence of seeding into adjacent areas. Similarly, the native bearberry *(Arctostaphylos uva-ursa*) from Manitoulin Island, reported by Sprent (1979) as actinorrhizal although nodules are rarely seen, has successfully established on the barrens and transition sites. These small patches show evidence of expansion. Incidental species transplanted at the same time included white spruce, common juniper *(Juniperus communis*), strawberry *(Fragaria virginiana*), field basil *(Clinopodium vulgare*), balsam ragwort *(Packera paupercula*), starflower, false Solomon's-seal *(Maianthemum stellatum*) and several species of aster and goldenrod (Winterhalder, 1996).

4.5.3 Native Seed Collection and Dispersal

In 1978, approximately 400 kg of seed from 14 species was collected and plots established on a five ha hilltop site (Chislett, 1983, Lautenbach, 1985). In 1979, 416 kg of native seed was mixed with commercial seed to treat 10 ha along Highway 144 opposite the Murray Mine and along Highway 17 East between Coniston and Wahnapitae. This program was not continued after 1979 despite its success. A wild berry plot was established 200 m east of this site.

Seed was collected from plants successfully growing in stressed environments to assess their tolerance to soil conditions and their ability to establish in lightly grassed areas (Chislett, 1983). Seeds were collected by cutting heads off plants at the time of seed maturity, tops were dried for three to four days, threshed and placed in shallow wooden boxes for seven to ten days. Seeds were stirred to complete the drying process. After drying, they were winnowed, screened, bagged, weighted and tagged (Chislett, 1983; Lautenbach, 1985).

Subsequent monitoring has confirmed that many native plant species will colonize the grassed areas if conditions are favourable without any further treatment. Transplanting species (as opposed to collecting seed) to reintroduce them to sites is more economical and equally effective (Chislett, 1983).

Native seed collected in 1978 and 1979 included the following (Chislett, 1983; Lautenbach, 1985):

- *Agropyron repens*
- *Deschampsia flexuosa*
- *Agrostis scabra*
- *Calamagrostis canadensis*
- *Deschampsia caespitosa*
- *Hordium jubatum*
- *Carex sp.*
- *Epilobium angustifolium*
- *Chrysanthemum leucanthemum*
- *Vicia cracca*
- *Trifolium repens*
- *Rumex acetacella*
- *Comptonia peregrina*
- *Quercus rubra*
- *Betula papyrifera*

4.5.4 Experimental Composting

A project was established in 1978 to examine the practicality of composting as a reclamation soil amendment strategy. Shredded newsprint, peat, pulverized garbage, vegetable waste, sawdust and sewage sludge were tested in a few composting pits. Plots were covered with plastic and temperature monitored. The pits were then covered with soil and seed during the last two weeks of summer to determine if this provided a suitable seedbed. Results showed high germination and growth. However, the experiment was discontinued due to high labour and material requirements (Chislett, 1983; Lautenbach, 1985).

4.5.5 Department of Biology Masters Program Studies, Laurentian University

Over the years, research has been carried out by a large number of master's students in the Department of Biology at Laurentian University studying soil chemistry, plant physiology and phytotoxicity, ecophysiology, soil microbiology, and plant response to a variety of soil amendment prescriptions. The results from many of these studies have been discussed in earlier sections of this chapter.

4.5.6 Vale Inco Ltd and Xstrata Nickel Research and Applied Programs

Both Xstrata Nickel and Vale Inco have treated their barren areas with a liming, fertilization and seeding treatment series since 1980 (Heale, 1995; 1991).

In 1980, Vale Inco Ltd. used a similar approach to the city's Land Reclamation Project on its private barren lands using all-terrain vehicles (Heale, 1991) and a crop dusting company to apply lime, fertilizer and seed on 650 ha (Heale, 1995). Vale Inco also participated in a joint calibrated watershed study, liming 37 ha of barrens at the east end of Daisy Lake (Beckett *et al.*, 1995). Vale Inco Ltd. also has a tree-planting program, planting jack pine and red pine (Heale, 1991). The conifer seedlings are raised in a mined-out drift 1400 m below ground in the Creighton Mine (Heale, 1987).

Sites are planted with primarily red pine and jack pine seedlings (Figure 4-15). Initial plantings followed the traditional forestry "row planting" design, however the program was modified to create groups of seedlings in a more natural pattern. Tree seedlings originally provided by the Ministry of Natural Resources are now purchased from commercial nurseries. Although most of the planting is undertaken with pine, a number of hardwoods are also planted on specific sites, for example yellow birch is replanted on moist telluric sites and red oak on dry upland sites. Over the years, non-native species were also planted, including European larch *(Larix decidua*) and the short-lived leguminous black locust, especially on silty clay-eroded sites (Winterhalder, 1987).

Recently, Vale Inco hired a commercial crop-dusting company to apply limestone, fertilizer and seeds from the air, treating 650 ha over four years. In 1994, 37 ha of near barren land at the east end of Daisy Lake was aerially limed as part of a calibrated watershed study (Gunn pers. comm., cited in Winterhalder, 1996).

Experimental Programs

Low Sulphur Tailings Test Plots: Vale Inco has tested the use of low sulphur tailings as a cover material. Lysimeter test plots were established, testing seepage chemistry and volume. The pH improved with a reduction in sulphur content but metal content remained elevated in lowest sulphur tailings (Lanteigne, 2001).

Biodiversity studies: Vale Inco has begun monitoring biodiversity in selected reclamation areas that have been treated with lime and fertilizer and seeded, followed by straw mulching to assist in germination and seed protection. Pine seedlings are planted once the graminoids are well established. These studies have shown that plant species increase over time, with native white birch, red maple, red oak and other deciduous species invading these areas without any additional assistance. Populations of spiders, mites and beetles have also increased as shown in studies of insects collected from the forest floor (Lanteigne, 2001).

CANMET and University of Western Ontario – Water cover research:

This partnership examined the use of bio-solids from the pulp and paper industry as a cover material on the tailings. Vegetation growth on the experimental plots showed excellent survival and growth. Monitoring of tailings pore water quality and metal uptake in plants is ongoing.

Tailings Waste Rock and Slag Co-Mixed as a Cover Material:

A study is underway to examine the effectiveness of this cover treatment (Lanteigne, 2001).

Figure 4-17 Regreening is evident in Falconbridge

4.5.7 Tailings Treatment

Tailings refer to the material that is discarded following milling and flotation of the ore. Thousands of hectares of tailings have been revegetated over the years using a grass and legume mixture (Heale, 1991; McLaughlin, 1983; Spires, 1975; Michelutti, 1974; Peters 1970; 1978; 1984; 1988; 1995). Conifer species have been planted on many of these grassed areas since 1972 (Winterhalder, 1996).

In some areas, wetlands have been created to treat acidic drainage from mine waste (Fyson *et al.,* 1995; Michelutti and Wiseman, 1995; Kalin and Smith, 1991). Vale Inco has developed a closeout plan to cover the high sulphur (15–20%) and pyrrhotite tailings with a layer of low-sulphur (0.4%) tailings (Heale, 1995) and raising the water table (Puro *et al*., 1995). Xstrata Nickel is also currently undertaking these measures at their site.

Xstrata Nickel has examined the use of water (Michelutti and Wiseman, 1995) or organic covers (Stogran and Wiseman, 1995) as oxygen barriers at some sites. In other areas they have created an impervious cap to prevent the entry of surface water and ground water flows around the tailings body (Woyshner *et al.,* 1995).

Approximately 1,250 ha of barren lands and 675 ha of tailings have been reclaimed by Vale Inco and Xstrata Nickel (Lautenbach, 1985).

4.5.8 Increasing the Genetic Diversity in Plant Populations in the Sudbury Region

By using molecular and cytological techniques, Xstrata Nickel in partnership with Laurentian University is establishing the level of genetic variation and diversity in Jack pine populations on impacted lands in the greater Sudbury Region. It is meant to direct diversity programs as a result of genetic instabilities and metal accumulations and to increase genetic variation in *Deschampsia cespitosa* populations.

4.5.9 Monitoring and Assessment by Laurentian University and Region of Sudbury

Laurentian University and the Region of Sudbury have conducted monitoring and assessment of treatment areas since 1979. Soil, soil microbiology, vegetation, insects and larger fauna were studied along permanent transects (Lautenbach, 1985). Early results indicated that:

- Vegetation cover in limed areas varied from 10 to 25%;
- Colonization of native species on treated sites was rapid and spontaneous;
- Plant cover rapidly increased;
- Nitrogen-fixing legumes grew much faster than grasses;
- Surface soil pH increased from 3.5 to 4.5 before treatment to 4.0 to 5.5 following treatment;
- Metals in grasses and tree species growing on reclaimed sites showed significantly elevated aluminium levels but only slightly higher levels of copper or nickel relative to sites that were not impacted; and,
- There was an increase in the number of insects, birds and some mammals in reclaimed areas compared to untreated sites.

4.5.10 MOE Long-term Monitoring

The Ontario Ministry of the Environment established long-term monitoring plots in the 1980s (Negusanti and McIlveen, 1990) and provided comprehensive data on changes in atmospheric emissions, soil chemistry, and metal uptake by selected plant species as part of the Acid Precipitation in Ontario Study (APIOS). The analysis of the data collected has shown continued reductions in the copper and nickel uptake by a variety of species.

Water quality monitoring by the Fisheries Assessment Unit has shown continuous improvements. Part of the improvements are attributed to the growth of vegetation on limed sites that has led to a reduction in overland flow, enhanced infiltration and greater movement of calcium deeper into the soil. This will help to stabilize stream-flow chemistry over time. The effects of the 1994 Daisy Lake catchment area liming project and the subsequent aerial liming of additional areas in the watershed by the mining companies near the inactive Coniston smelter continues to be monitored (Pitblado and Gallie, 1995; Gunn, 2005 pers. comm.).

4.6 Teams Overseeing Regreening Activities

This section identifies specific groups with past and current involvement in regreening initiatives.

4.6.1 The Sudbury Environmental Enhancement Programme Committee

In the 1960s, a group of concerned citizens became involved in several key organizations that had the mandate to trigger and deliver an effective land reclamation program. These individuals formed a partnership to lead other concerned citizens, forming the Sudbury Environmental Enhancement Program (SEEP) in 1969. Ted McHale and Ed Kraker of the Ontario Department of Lands and Forests and Dr. Gerard Courtin and Keith Winterhalder from Laurentian University's Department of Biology provided the early leadership for the program that developed (Winterhalder, 1983a).

SEEP developed into a partnership between the Ontario Department of Lands and Forests (Sudbury District Timber Branch) and Laurentian University Biology Department after Vale Inco's announcement to build the 381 m tall stack. In the belief that improved air quality would allow the continued survival of vegetative growth if seedlings could be established in the region, the group developed an experimental tree-planting program on a barren site near Coniston and in stunted, partially barren, red oak woodlands near Skead to determine an effective operational program for regreening.

The objectives of the program were as follows:

- To determine the capability of the existing soil medium to support growth and to assess the need for soil amendments;
- To conduct soil analysis to determine the limitations to growth and effective levels of soil amendment; and,
- To plant thousands of bare root nursery stock of 29 native and exotic species near Coniston (barren, sandy floodplain), Skead (semi-barren sites on deep gravel dominated by red oak) and on a sandy control site.

4.6.2 Vegetation Enhancement Technical Advisory Committee

In 1973, the Region established a multidisciplinary technical advisory group that was given the mandate to modify Sudbury's reputation as a barren, inhospitable, unattractive community (Lautenbach, 1985). Members from a number of community interest groups including Laurentian University, Vale Inco, Xstrata Nickel, the Ontario Ministry of Environment, Ontario Ministry of Natural Resources, Northern Development and Mines (Northern Affairs) and the local Conservation Authority were brought together as an advisory group for the regional government. The committee, formally established on October 3, 1973, was initially referred to as the Technical Tree Planting Committee (TTPC). In 1978, the committee was renamed the Vegetation Enhancement Technical Advisory Committee (VETAC) under which it continues to operate today.

The committee identified three major goals:

- Vegetate barren areas in key community areas (*e.g.*, local parks, adjacent to schools), and along major highways;
- Distribute tree seedlings to residents; and,
- Encourage the replanting and revegetation of vacant lands in the communities (Lautenbach, 1985).

Funds were insufficient to operationalize the program (Lautenbach, 1985); however, the committee published a tree planting brochure to distribute to residents, hosted an annual garden show to encourage landscaping, encouraged and oversaw monitoring programs, and continued to support funding for research.

At the same time, regional council approved the 1978 Regional Official Plan for the Sudbury Planning Area, which included an objective to enhance the region's visual quality and image by means of land reclamation efforts on disturbed lands. Council made a commitment to support and fund applied research that would contribute to the land reclamation program (Lautenbach, 1985).

FIST (Forest Inventory Student Team) Experimental Plots

In 1974 and 1975 the Technical Tree Planting Committee of the Regional Municipality of Sudbury (now VETAC) commissioned the Laurentian University Biology Department to survey barren and semi-barren sites along roads and railways (Winterhalder, 1975). Students working under FIST established plots on representative barren and semi-barren transition sites to determine the growth and survival of commercial and native mixtures and to test reclamation procedures (Chislett, 1983).

Jane Goodall Trail

The one km "Jane Goodall Reclamation Trail," located next to the Welcome Centre at the corner of Hwy 17 East and Garson-Coniston Road, was officially opened on May 7, 2002. The trail was developed under the supervision of the Sudbury Land Reclamation Program through the efforts of a number of volunteers and employees. The history and results of liming, grassing, and tree planting, and two lookout points illustrate the healing of the landscape.

4.6.3 Junction Creek Stewardship Committee

The Junction Creek Stewardship Committee, established in 1999, has been involved with reclamation activities in the Junction Creek watershed. The Committee has been involved in promoting and organizing events that improve both the terrestrial and aquatic environments. The committee has promoted several tree planting initiatives, stream and shoreline clean up, and in-stream rehabilitation. The group is currently (2005) launching Phase 2 of their "adopt a creek program", supporting five new groups.

4.6.4 Collège Boréal

Collège Boréal, under the leadership of their Resource Technician Program, has provided teaching and employment opportunities for their students through growing seedlings for shoreline planting and providing technical help with mapping treated areas and candidate areas for future treatment.

4.6.5 Nickel District Conservation Authority and the Sudbury Regional Tree Fund

The Nickel District Conservation Authority (NDCA) owns and operates the Lake Laurentian Conservation Area, which encompasses 920 hectares of land within the City of Sudbury. Various community groups, including Boy Scouts of Canada, and school groups have carried out liming and tree planting there. Most recently, trees were planted under the open and closed white birch mixed wood canopy through the Sudbury Regional Tree Fund. Approximately 1,000 white pine, red pine, eastern white cedar and larch (*Larix laricina*) are planted each year in the Tom Davies Commemorative Forest, named after the former Chair of the Regional Municipality, Tom Davies.

The NDCA also administers funding and provides technical expertise for the Junction Creek Stewardship Committee. It also allows access to funding programs for partnering community groups.

4.6.6 The Region of Sudbury Land Reclamation Program: Organization and Funding

The Regional Planning Department, under the leadership of planner Bill Lautenbach, suggested that some of the student jobs lost through technological improvements to the mining sector be recaptured through employment in a major land reclamation program (Lautenbach, 1985). The Regional Municipality dedicated $53,000 to cover capital costs. These were matched by the Ontario Ministry of Northern Affairs. The Federal Government, through its Young Canada Works Program, supported the labour component of $192,000 (Lautenbach, 1985). This enabled the Regional Land Reclamation Program to become operational in 1978.

Over 170 students were hired in the first year to apply lime, fertilizer and seed to barren areas along Hwy 541 to the Sudbury Airport and Hwy 17 East from Coniston to Wahnapitae (Lautenbach, 1985; Chislett, 1983). Specific details for the first year are summarized in Table 4.4. Additional employment was provided to carry out complementary field and office activities.

Table 4.4 Summary of the First Year of the 1978 Land Reclamation Program

Activity	Employment		Labour Costs	Capital Costs	Total Costs	Accomplishments
	# Persons	# Work Weeks				
Grassing and Greening	82	624	$81,498	$57,272	$138,770	114.8 ha of barren or semi-barren area reclaimed
Site improvement	40	524	$62,342	$9,737	$72,079	206.3 ha of damaged area site improved
pH, nutrient sampling	15	192	$24,218	$1,827	$26,045	completed intensive sampling of proposed grassing areas, 30,000 samples taken
Native seed collection	20	141	$18,602	$1,897	$20,499	365 kg seed collected for 15 native species
Transplanting	6	72	$9,124	$1,427	$10,551	Transplanted 6,000 trees, shrubs, and herbs to six experimental sites
Composting	8	105	$11,399	$1,993	$13,392	122 test plots established at 3 sites
Administration	3	48	$55,429	$6,731	$12,160	Office support (payroll, equipment)

Source: Audited financial statements as reported in Lautenbach, 1985.

Five-Year Land Reclamation Plans

In 1980, the first of several formal Five-Year Land Reclamation Plans guiding reclamation activities (1980–1984) was prepared. Every five years there is another review, and a community workshop is held to reflect on and refocus the program.

Program Funding, Expenditures and Employment to 2005

The Sudbury Region's Planning and Development Department administered the reclamation program. This responsibility was moved to the Chief Administrative Officer and a Land Reclamation Coordinator was appointed to oversee the program (Lautenbach, 1985). Three to six regional employees assisted in field supervision and other departments (*e.g.*, legal, accounting, *etc.*) provided support. Technical advice, contacts with specialized skills, and research capability was provided by VETAC (Lautenbach, 1985).

By 2005, the total number of temporary employment positions created exceeded 4,400, the total area of the total number of tree seedlings that had been planted was nearly 8.5 million, and total costs for the Land Reclamation Program were nearly $23.5 million (City of Greater Sudbury, 2005).

Funds have been provided by the following programs:

- Canada Employment and Immigration Commission (Summer Canada Program, Canada Community Development Program,
- ILAP/Canada Works Program;
- UI/IC Forestry Sector Program;
- Mining Sector Work Program;
- Canada /Ontario Employment Development Program;
- Canadian Forest Service;
- Ontario Ministry of Northern Affairs;
- Ontario Ministry of Natural Resources Mining Section Work Program;
- Ontario Ministry of Labour: Canada/Ontario Employment Development Program;
- Ontario Ministry of Municipal Affairs and Housing;
- Regional Municipality of Sudbury; and,
- other private sources (Lautenbach, 1985).

4.7 Benefits of Regreening

4.7.1 Overview

The regreening program has created a more attractive landscape, enhancing the public image of Sudbury. From an ecological perspective, the program has reduced soil erosion, improved water quality, reduced the availability of metals in the soil and therefore phytotoxicity. This has facilitated the natural recovery of vegetation in the region, and has increased the biodiversity of both plants and wildlife. The changes to the plant cover in the region are dramatic, as illustrated in Figure 4-18.

Figure 4-18 Martindale Road, Sudbury, early 1980s and 2001 (Photos courtesy of Keith Winterhalder (top) and David Pearson (bottom))

Some of the original objectives of the Land Reclamation Program were summarized by Lautenbach (1985) as follows:

- Reclaim barren land and improve the region's image;

- Provide summer employment for students;
- Prevent soil erosion and maintain a valuable soil base; and,
- Add to current land reclamation knowledge.

The program has contributed substantially to each of the objectives. The program has provided summer employment for more than 1,200 students since its establishment in 1978 and transitional employment for many others. The program both directly and indirectly has promoted and supported basic research to better understand plant physiology with respect to the establishment, growth and development of different species in both untreated acidic, metal enriched soils and on sites specifically prepared to create more favourable growing sites. It has also facilitated research into the social and economic environments that can effectively launch and support reclamation activities in other jurisdictions.

The program has successfully met the overriding original mandate of the Land Reclamation Program in 1978 to create conditions that changed the image of Sudbury from a barren undesirable place to live to an environmental "success story". Specific benefits are described in more detail below.

4.7.2 Metal Detoxification

The manual application of ground dolomitic limestone with or without the addition of fertilizer has successfully promoted vegetation growth in many areas. The standard regreening treatment series has reduced the acidity of the soils sufficiently to trigger the successful germination and establishment of native species through both seeding interventions and through natural colonization processes (Winterhalder, 1995). The lime applications have also stimulated the coppice regrowth of native white birch and trembling aspen. The rooting systems of these trees are now extending deeper into the soil, increasing the cycling of selective nutrients by drawing basic captions from depth into the plant biomass and returning nutrients to surface soils through the annual application of deciduous foliage to surface soils.

Detailed laboratory soil toxicity trials being undertaken as part of Objective 1 of the ERA (refer to Volume III) will provide further information on the levels of specific metals that inhibit plant growth, and the interactions between metals and soil pH.

4.7.3 Improvements in Site Aesthetics

Improving the aesthetics of the community and primary access routes into Sudbury was one of the primary objectives of the 1978 Land Reclamation Program. Success of this is evident with the establishment of 20 to 30 year old conifer plantations along the Highway 17, Highway 69 and Hwy 144 corridors, major bypasses and many of the major roads in the Sudbury region (Winterhalder, 2002).

The application of grass-legume mixtures and the tree-planting program over the past 20 years has "greened" many formerly barren areas. Mixed pine-birch forests and upland red oak forests are common around many of the residential and school areas in Sudbury. Each year, new recreational trails or trail segments are established in the young forests.

The establishment of a vegetation cover has stimulated the successful germination of in-blown seeds of a variety of native and non-native seed origin species, increasing the diversity of plant cover and enriching the textures of the landscape. Many of the planted trees are now sufficiently mature to produce seed that contributes to natural infilling between and around the planted trees.

4.7.4 Natural Recovery of Ecosystems

The successful re-establishment of a variety of forest communities in the Sudbury Region has provided a favourable environment for an increasingly diverse population of insects, birds and mammals (Lautenbach, 1986). The care that the program has taken to match species with those that are thought to have been present in pre-disturbance forests has created viable self-sustaining communities that are well suited to various landscape positions. Although the structure and species composition of these communities is less complex than that of natural systems, the principal components of the ecosystems for those site locations are often present. Over time, natural revegetation processes are adding to species diversity of these communities.

Both liming and the establishment of plant communities have also triggered the slow recovery of the soil. Soil pH levels have increased by more than one pH unit. This continues to create more favourable germination conditions for a wider variety of plant species. The continued growth of vegetation in many areas of the region also contributes to leaf and woody litter, adding organic matter to the site. The successful establishment of forests also increases the retention of leaf litter, which is increasingly incorporated into the soil. This is most beneficial in areas where this surface organic matter would be annually lost through wind and water erosion.

4.7.5 Socio-economic Benefits

Sudbury is now known for its successful regreening program, which is held up as a successful environmental community/industry partnership. The transformation of the industrial landscape into an aesthetically pleasing community has been the subject of many conference papers. In addition, it has provided the flagship for several environmental conferences. For example, the 1978 Sudbury Conference, the 1990 Healthy Places Healthy People Conference, and the 1995, 1999, 2003 and 2007 Sudbury Mining and the Environment Conference. The program has developed a new entrepreneurial expertise in the development of effective community/industry/research partnerships (Gunn, 1996).

Effective partnerships have been forged between industry, government, academia and the public. These groups continue to be willing to remain flexible, to focus on achievable goals and to continue to encourage and facilitate the direct involvement of the public (Gunn *et al.,* 1995). This has led to three main achievements, which have increased the stability of the community: gainful employment, image improvement, and environmental rehabilitation.

4.8 Future Directions

Periodic reflection and strategy development is part of the history of the Regreening Program. Public workshops were held on February 22 and 23, 1996, coordinated by VETAC (Gunn, 1996), to develop a five-year program to direct future work. Every five years, there is another review, and a community workshop is held to reflect and refocus the program.

There continues to be a need to provide direction in an environment of reduced public funding for regreening and where sites needing treatment (liming and planting) are not as easily accessible. Over 100 community members participated in the Land Reclamation Program planning workshop in 1996 with 89% indicating that regreening was very important. They recommended that land reclamation concentrate closer to the major population centers, for example adjacent to schools and city subdivisions, and that the program concentrate on restoring whole ecosystems (watersheds). This was an evolution from the historic tree planting programs that created buffer “view strips” along the major roads and highways of Sudbury.

The next decade of the program continued to focus on creating special places for the community. These special places included the establishment of memorial forests and the creation of a “ribbon of life” surrounding key lakes to improve drainage. In turn, these initiatives led to education opportunities and recreation, and to the establishment of a trust fund with charitable donations.

The recent five-year review of the program has focused on improving the quality of the environment as the primary objective, concentrating on land reclamation activities to achieve the larger goal of ecosystem restoration and community health. The emphasis is on treating watersheds and completing an accurate inventory of the state of the natural vegetation in the region. This inventory has extended into the urban residential area to provide the basis for designing a program that is consistent with the overall regreening program.

The program continues to encourage community volunteers, for example by expanding and supporting the "adopt a hill to restore" and "adopt a stream" programs. At the same time the mining companies continue to concentrate their resources and to support aerial liming. The planting programs continue at 1996 rates of 200,000 to 300,000 trees per year (Gunn, 1996) with occasional increases where special funding sources are made available. For example, the local forest management company tapped into funds from the provincial Forestry Futures Trust to plant areas outside the main urban core.

The information collected as part of the continually evolving regreening program and associated monitoring continues to provide professional and operational expertise that can be exported to other communities and post-mining reclamation initiatives. The compilation of the lessons learned from the reclamation and regreening programs provides a marketable product if effectively packaged and marketed.

The program also continues to provide outdoor learning laboratories for fostering an environmental ethic and an understanding of applied research skills for all ages in the community from elementary school through to adult learning. The successful reestablishment of forest cover has fostered the development of community-supported trail systems that promotes citizen activity and health.

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